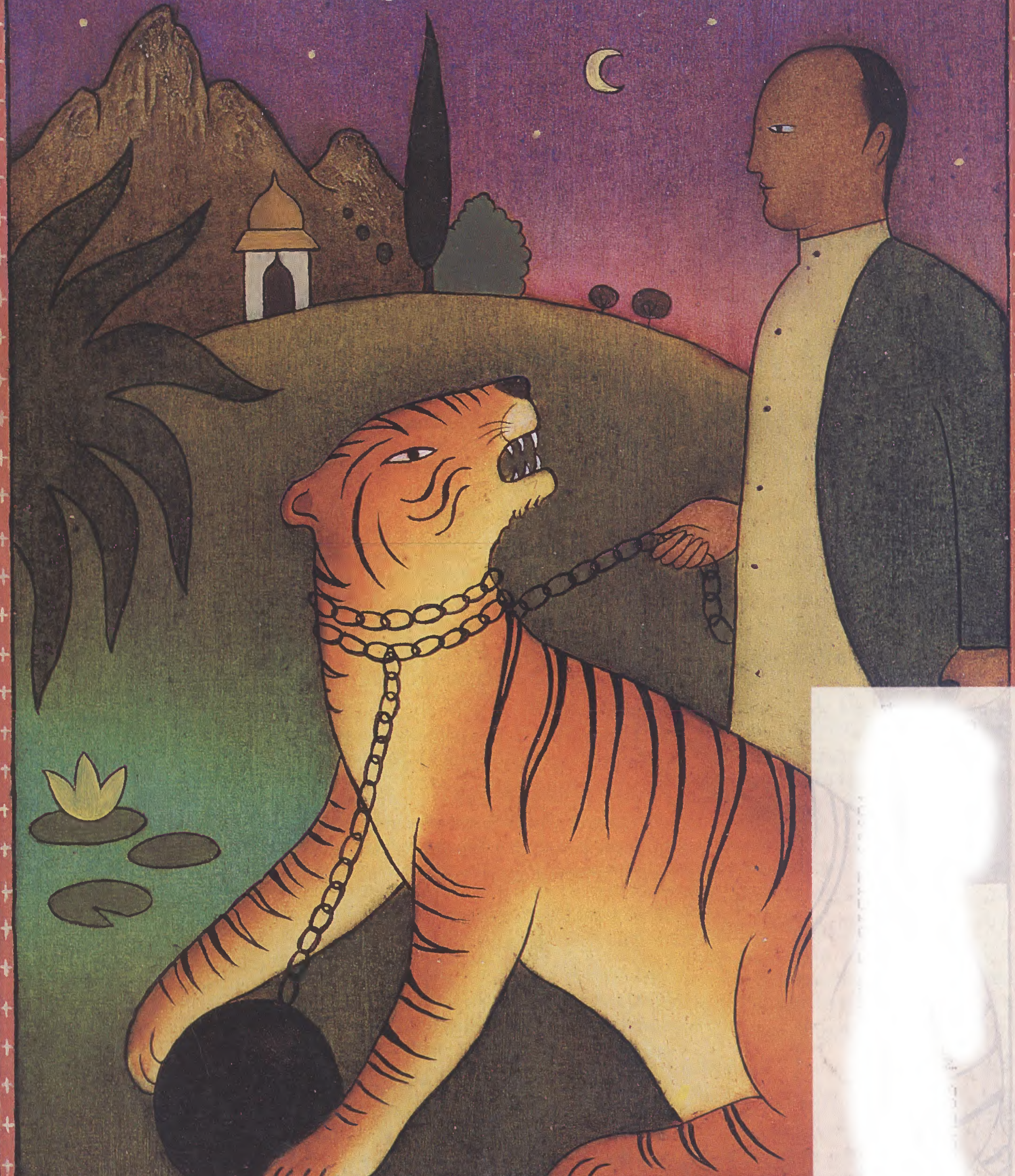
IEEE
SPECTRUM

TECHNOLOGY IN INDIA

Bureaucracy slows innovation, growth



MARCH 1994 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

Newslog

JAN 4. MCI Communications Corp., Washington, D.C., announced a US $20 billion plan to create, with partners, a multimedia information superhighway by the end of the decade. Using underground conduits it acquired from Western Union Telegraph Co., MCI initially plans to build local optical-fiber networks in the nation's 20 biggest cities, in order to bypass phone exchanges operated mainly by the seven regional Bell companies. MCI now pays over $5 billion annually in access charges.

JAN 5. A board of engineers and scientists after a four-month investigation said the $980 million **Mars Observer** mission failed last August most probably because of a sudden rupture of a fuel line. The leaking fuel might well have sent the spacecraft spinning out of control, triggering an emergency shutdown. The board also criticized the **National Aeronautics and Space Administration** for its management of the project and the spacecraft design.

JAN 7. Three big job reduction announcements in the telephone industry included **Pacific Telesis Group,** San Francisco, which said it would slash 3000 jobs this year and 7000 more by the end of 1997, or 19 percent of its workforce. Then on Jan. 10, **GTE Corp.**, Stamford, Conn., announced it would cut 17 000 jobs—more than one of every five of its local phone workers and managers—during the next three years. And on Jan. 24, **Nynex Corp.**, New York City, said it would cut 16 800 employees by late 1996.

JAN 10. Reliance Electric Co., Cleveland, Ohio, said it had operated a superconducting motor with an output power of 3730 W and rotating high-temperature superconducting (HTS) coils at a speed of 1800 rpm. The new motor is a significant step beyond Reliance's prototype that had stationary HTS coils and a lower output power of 1490 W.

JAN 11. Westinghouse Electric Corp., Pittsburgh, said it would lay off 3400 employees and a further 2600 through attrition within the next two years. The company's worldwide head count will then fall to around 48 000 employees.

JAN 13. U.S. space officials declared the repairs on the orbiting **Hubble Space Telescope** a complete success. The chief repair, accomplished by spacewalking astronauts in December, was to fix a flaw in the telescope's primary mirror. Now Hubble can observe objects as far as 10 billion to 12 billion light-years away, almost to the edge of the visible universe.

JAN 14. The **Latvian government** said it had awarded a contract to modernize the country's telecommunications network to a consortium headed by the United Kingdom's **Cable & Wireless.** In a 10-year plan, C&W and **Telecom Finland** will install 650 000 new digital telephone lines, almost doubling Latvia's phone capacity. The deal is the first internationally tendered privatization of a state telecommunications operator in the former Soviet Union.

JAN 17. IBM Corp. said it had signed an exclusive agreement with the **International Olympic Committee** to provide computer systems for the next four Olympic Games. This is the first time the committee has selected a single company to supply the Games' information technology systems. The deal will allow systems developed for one year's Games to be moved easily to the next Games. Previous Olympic systems had generally been developed from scratch each time at significant expense.

JAN 18. ABB Asea Brown Boveri, Zurich, Switzerland, said it had won an order worth over $100 million from **Kraftwerke Gera**, Germany, for a combined heat and power plant at Gera, near Leipzig. The station, to be in operation by mid-1996, is to deliver 76 MW of electricity and 250 MW of thermal energy for the local district heating system.

JAN 19. Russia's communications minister said the Russian phone company **Rostelecom** had set up a joint venture with **US West**, Denver, Colo., Germany's **Deutsche Bundespost Telekom**, and **France Telecom** to add 20 million new telephone lines in Russia within 10 years, doubling the present capacity. Dubbed "50×50," the project will link 50 cities with 50 000 km of optical-fiber cables.

JAN 19. The U.S Energy Department said a cooperative research program with **Energy Conversion Devices Inc.**, Troy, Mich., and Japan's **Canon Inc.** had produced a new amorphous silicon solar cell that could halve the cost of solar energy for the home. Incorporating this material into roofing shingles could supply a home with electricity at a cost of $0.16/kWH and eventually $0.12, versus $0.25–$0.50 for electricity from today's conventional photovoltaic cells. The new photovoltaic solar cell has an efficiency of 10.2 percent, a record for amorphous silicon.

JAN 21. A joint research team of **NEC Corp.**, Tokyo, and the **California Institute of Technology,** Pasadena, said it had devised a sensor-covered "snake" robot that can detect obstacles in its path and weave around them. Needing neither commands from operators nor knowledge about the distance to obstacles, it is suitable for work on blind spots or in places where obstacles may arise unexpectedly. The robot is built with 20 infrared-ray and 10 supersonic distance sensors.

JAN 24. The U.S. Commerce Department announced that at this time the United States would retain its system of awarding patents on the basis of the date of invention, rather than the date of application used by other industrial countries. The move delays international negotiations, which began a decade ago, aimed at bringing the world's patent laws into harmony on the first-to-file basis.

JAN 24. Telesat Canada said that a powerful geomagnetic disturbance had crippled two Canadian communications satellites, disrupting television and radio throughout the country as well as some telephone and data services. One satellite, Anik E1, was repaired by instructions from earth, but Anik E2 may have to be written off. Static electricity had previously interrupted satellite service, but never so extensively. The incident knocked out power to the flywheels that keep the satellites pointing in the right direction.

JAN 31. Japan's **Kinki Mobile Radio System Inc.** said it had developed a new signal-processing method that enables faxes to be sent from a mobile telephone. Transmission was made over an 800-MHz band at a speed of 9600 b/s. An A-4 size document was transmitted in about 1 minute. To make a prototype device, the company plans to team up with fax manufacturers.

JAN 31. Comsat Corp., Bethesda, Md., which provides satellite networks and other communications gear, said it would buy telecommunications-maker **Radiation Systems Inc.**, Sterling, Va., for about $150 million. The two companies will join forces to serve the wireless communications market.

Preview:
MAR 3. The **National Aeronautics and Space Administration** is to launch the space shuttle **Columbia** from Kennedy Space Center in Florida. During the 14-day mission, the crew will study materials processing in the microgravity environment of space flight.

Sally Cahur

MARCH 1994 / VOLUME 31 / NUMBER 3

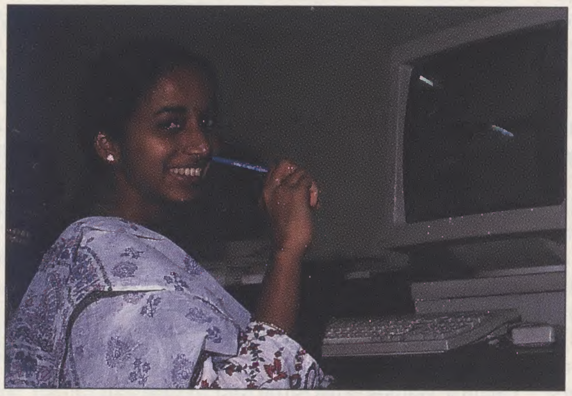
IEEE SPECTRUM

SPECIAL REPORT

TECHNOLOGY IN INDIA

Glenn Zorpette (photos)

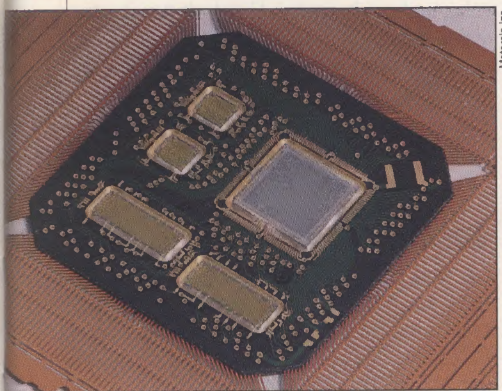
Built in 1753, the tomb of the ruler Safdar Jang in New Delhi has been called the "last flicker of the lamp of Moghul architecture."



Students take a break from their studies at the Centre for Artificial Intelligence Research in Bangalore.

A tree provides relief from the midday sun at radiotelescope construction site at Narayongaon, in western India.

PACKAGING



Motorola Inc.

TUTORIAL

Cover: A tiger lurks in India and could be about to break its bonds. Representing India's talented entrepreneurs, innovators, and technologists, the tiger has so far been chained by government bureaucracy as in this painting executed in traditional Indian style by artist Stefano Vitale. See p. 24.

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POSTMASTER: Please send address changes to IEEE Spectrum, c/o Coding Oepartment, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855. Second Class postage paid at New York, NY, and additional mailing offices. Canadian GST #125634188.

Printed at 8649 Hacks Cross Rd., Olive Branch, MS 38654, U.S.A.

IEEE Spectrum is a member of the Audit Bureau of Circulations, the Magazine Publishers of America, and the Society of National Association Publications.

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HEADQUARTERS: New York City 212-705-7555
BUREAUS: *WASHINGTON, O.C.,* John A. Adam, 202-544-3790; *SAN FRANCISCO,* Tekla S. Perry, 415-282-3608

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EOITORS BY E-MAIL:

John A. Adam	j.adam@ieee.org
Trudy E. Bell	t.bell@ieee.org
Richard Comerford	r.comerford@ieee.org
Linda Geppert	l.geppert@ieee.org
Gadi Kaplan	g.kaplan@ieee.org
Tekla S. Perry	t.perry@ieee.org
Michael J. Riezenman	m.riezenman@ieee.org
Alfred Rosenblatt	a.rosenblatt@ieee.org
Murray Slovick	m.slovick@ieee.org
Glenn Zorpette	g.zorpette@ieee.org

Editorial Board

Forum

Authors in orbit

Viktor Kudielka's letter [June 1993, p. 8] is slightly misleading, so I would like to make some corrections.

I had never even seen Noordung's (Potočnik's) 1929 book when I wrote my 1945 *Wireless World* article, but I had seen pictures of his space station (precursor of the one in *2001*) in science fiction magazines. His work was obviously of such importance that it merited a reference, but the concept of the geostationary orbit much predates it, going back at least to Tsiolkovsky at the beginning of the century. And, as I pointed out in *How the World Was One* (Bantam, 1992), Hermann Oberth anticipated Potočnik by almost five years. He was the first to suggest the use of space stations for communications—though by optical means, not radio, then still in a very primitive state.

As it happens, only in 1993 did I obtain my first copy of Potočnik's classic book, and I was astonished to see that he did, in fact, envisage the use of short waves for communications between earth and the station. I am sure if TV had existed when he wrote it, he would have pointed out the advantages of the geostationary orbit for global broadcasting, which was the main point of my 1945 paper.

Finally, I would like to mention an even more amazing anticipation—Edward Everett Hale's *The Brick Moon* (1870), which contained the very first proposal for an artificial satellite—as a navigational aid! Shades of GPS....

Arthur C. Clarke
Colombo, Sri Lanka

GPS: time and change

From my perspective, Ivan Getting ["The Global Positioning System," December 1993, pp. 36–38, 43–47] overstates the role of Aerospace Corp. and ignores the fundamental contributions of the Naval Research Laboratory (NRL) to the development of the GPS. The GPS uses passive ranging, 12-hour circular orbits, and space-borne atomic clocks that were originally implemented by NRL in the Timation navigation satellite system. In turn, the ancestry of Timation can be traced to Project Vanguard and the Navy Space Surveillance System, for which NRL also had primary responsibility.

The simple fundamental concept of GPS is the ability to measure range to a transmitter passively if the user and transmitter have synchronized clocks. If the user passively measures the range to four (or more) transmitters that carry synchronized clocks and are at known positions, the user can determine clock time and position in three dimensions.

This concept first was demonstrated to Chester Kleczek and John Yob of the Naval Air Systems Command in 1964. They understood that the concept could be used to improve aircraft navigation, and so they promptly funded development of a system, which was later named "Timation" for TIMe navigATION.

The first Timation satellite was launched on May 31, 1967, and demonstrated the feasibility of the passive-ranging concept. After initial tests and calibration at the naval laboratory, the technique was demonstrated to personnel of the Department of Defense and the Department of the Navy at the John Ericsson statue in Washington, D.C., near the Lincoln Memorial.

The Timation II satellite was launched on August 30, 1969. Timation III, renamed NTS-1 (Navigation Technology Satellite), was launched on June 14, 1974, and carried quartz and rubidium time standards. NTS-2 was launched on June 23, 1974, as the first of the GPS Phase-I satellites. It carried cesium-beam standards and transmitted signals for both Timation and Navstar GPS receivers. The first studies of satellite constellations were made by NRL (Report 7389—"TIMATION Navigation Satellite System Constellation Study").

Roger Easton
Canaan, N.H.

The problem with GPS as primary navigation for civil aviation is not technical, but political ["Flight observations," January 1994, p. 6]. As long as the U.S. Department of Defense controls the systems and retains the right to degrade service (selective availability and anti-spoofing), or even shut it down without notice, no responsible authority could accept it. Satellite drift has no bearing on the situation. The orbits are checked by ground stations all the time, and the satellites transmit correct locations and time whenever they are permitted.

Rodney Myrvaagnes
New York City

Remembering the flat panel

Kenneth Werner's fine article "The flat panel's future" [November 1993, p. 18–26] brought back memories of the General Electric Co.'s Electronics Laboratory in Syracuse, N.Y., where I was a Massachusetts Institute of Technology co-op student in 1955–56.

The development of a color television display tube was a major mission of the laboratory, which was directed by Lloyd Devore. Hanging on the wall of his office was a flat gray framed panel designated "the Picture on the Wall TV." Thinking was already going on 40 years ago about a flat-panel color TV, felt then to be the next step beyond the color CRT.

As I recall, crossed-wire devices similar to gaseous displays or spark chambers were discussed. Transistors were just emerging into the commercial venue, and localized excitation of a fluor by hordes of transistors was put forth. Who could even think of LSI and submicrometer spacings of millions of devices!

GE never did develop a commercial color tube, and not long after dropped out of television entirely. I did get a master's thesis out of another phase of the laboratory's work in color TV.

Samuel C. Goldman
Canton, Mass.

Solving the problem

Oh, how I agree with Robert Lucky ["Technology isn't the problem," November 1993, p. 14] about the scant recognition engineers get for essentially creating much of the wealth in our post-industrial society.

For instance, will Larry J. Hornbeck, inventor of the digital micromirror device ["Mirrors on a chip," November 1993, pp. 27–31] ever get the public recognition that should be his if that technology revolutionizes flat displays? Not very likely.

Another good example would be engineering physicists J. T. Randall and H. A. Boot, who at Birmingham University in the United Kingdom invented and perfected the magnetron in 1940. This device increased the output power of the British coastal radar transmitters by several orders of magnitude, probably contributing more than anything else to the final defeat of the Luftwaffe. These days the magnetron is the essential component in every microwave oven. Are the names of the inventors household words? Not exactly.

The list of unsung scientists and engineers is long because of the inability of the average voter and elected politician to relate to these sorts of accomplishments or to recognize the immense value of the contributions that engineers and scientists have made to health and the quality of life.

One small step toward redressing the imbalance in the decision-making arena would be for the scientific and engineering community to push for the appointment of

permanent scientific and engineering advisors in national and regional legislatures. These people would be appointed, based on their contributions to science and engineering and their ability to communicate, by impartial panels drawn from industry and academia. They would participate directly in debates on issues that required scientific and engineering expertise for their resolution. The votes would be recorded, but only the votes of the elected representatives would be counted. That arrangement would ensure that the balance of power would not be threatened.

There are those who will ask: "If the balance of power is not changed, why bother?" The answer is that issues such as jobs versus pollution, the feasibility of regulating new technology, and realistic schedules for zero-emission vehicles would have direct input from knowledgeable scientists and engineers while they were being debated. The advisors' opinions would be the subject of public scrutiny and attention.

Our society is becoming ever more fearful of the rapid advances in science and technology, which it sees as increasingly difficult to predict or control. Such an approach to getting more qualified people into the decision-making process might therefore find some support outside, as well as inside, the scientific and engineering community.

Quentin Bristow
Ottawa, Ont., Canada

Don't make problems

I would like to respond to Samuel A. Bogen's letter [December 1993, p. 7]. Bogen advises in some situations not to call a female associate by her first name "even if it is for the worthy purpose of showing that you have a woman associate."

What worthy purpose? What reason is there ever to make an issue of a colleague's gender or race or any other physical characteristic? Please, don't make me be a Woman Engineer; just let me be an engineer.

Laura M. Steffek
Wisconsin Rapids, Wis.

Calibration certification

As president of the American Association for Laboratory Accreditation, it is my responsibility to keep abreast of the current trends in testing and calibration. I believe the article "Test and measurement" by Michael J. Riezenman [January, pp. 54–57] overestimates the value of ISO 9000 for trading in Europe.

In fact, calibrations that are acceptable throughout Europe must come from either the national laboratories in a country or laboratories that have been accredited by one of the national laboratory accreditation systems to requirements in ISO Guide 25. The applicable standard for calibration is Guide 25, not ISO 9000.

Calibration certificates, to be acceptable in nine European countries that have a formal agreement on acceptance of each other's calibration certificates, must carry the logo of the accreditation organization, and these organizations use ISO Guide 25 as their requirement.

In the United States, the National Conference of Standards Laboratories is developing a new American National Standard for calibration laboratories. It, too, is based on Guide 25.

John W. Locke
Gaithersburg, Md.

Post hoc, non ergo propter hoc

Marvin R. Heembrock's letter "On Spectral Lines" [January, pp. 8–9] commented on an earlier column regarding the possible unethical behavior of engineers in what may have been fraudulent test results in the Strategic Defense Initiative (SDI). In his defense of the engineers' possible deception in presenting test results, Heembrock states that "the threat of SDI, whether real or fabricated, was a major factor in the collapse of the Soviet Union." This statement of supposed fact is unsupportable.

As an engineer, Heembrock should know that any conclusion of a causal relationship between the existence of SDI and the collapse of the Soviet Union is nothing more than informed speculation at best. We have not performed, and are unable to perform, the experiment wherein the initiative does not exist under the same economic conditions that existed in the Soviet Union in August 1991.

That is to say, we cannot find out if the Soviet Union would have collapsed in the absence of a "real or fabricated" SDI. The statement that "if A follows B, then B caused A" is as flawed a piece of logic as anyone will ever see. Heembrock may very well believe that SDI contributed largely to recent changes in the government of the former Soviet Union, but he cannot know it to be a fact.

Jerome Peirick
St. Louis, Mo.

Clearing up EMI

Forum has proved very useful to me over the years for communicating facts and ideas of general interest. I would like to mildly protest the editors' penchant for rewriting material, probably for brevity or perceived clarity, which may alter meanings.

In my letter on "In-flight EMI" [December 1993, p. 6], I had written to the effect that it is difficult to see how "plane waves" could be launched inside a congested box, trying to convey that their scattering through holes may not be a useful model for EMI. However, by transposing my negative statement to a question: "How could such waves be generated...?," followed by the added phrase "To begin with...," it appeared that I was trying to explain how "plane waves" are, in fact, generated.

Leslie C. Hale
University Park, Pa.

Corrections

In "Help from Cyberspace" on p. 15 of the November 1993 issue, the IP address of ftp.microsoft.com should have been 198.105.232.1:21.

On p. 70 of the issue, the Survo 84C software package for statistical analysis and related areas sells for US $400–$950. The contact is Survo Systems Ltd., Kuninkaantentammentie 7, 00430 Helsinki, Finland; fax (358 + 0) 566 8146. (Note that 0 is the area code for Helsinki.)

In the fourth line of Washington Watch on p. 66F of the December 1993 issue, the phone number should have been 1-800-ATP-FUND.

On p. 50 of the January issue, the energy consumed by desktop computers should have been described as an estimated 5 percent of U.S. commercial (nonindustrial) electricity use. On the next page, two silicon-on-insulator memory devices should have been a 512-kb static RAM from IBM Corp. and a fully functional 64-kb dynamic RAM test device with 0.5-μm design rules from Mitsubishi Electric Corp.

On p. 62 of the same issue, in the seventh line of the fourth paragraph, the total weight of the flywheel battery should have been given as 460 kg.

On p. 16 of the February issue, the photographs of software packages should have been transposed. The SystemView photograph belongs in the left-hand column and the BBN/Cornerstone photograph in the middle column.—*Ed.*

Readers are invited to comment in this department on material previously published in *IEEE Spectrum*; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Short, concise letters are preferred. The Editor reserves the right to limit debate on controversial issues. Contact: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, NY 10017, U.S.A.; fax, 212-705-7453. The e-mail (Internet) address is n.hantman@ieee.org. The computer bulletin board number is 212-705-7308; the password is SPECTRUM. The line parameters are 1200 bits per second, no parity, 8 data bits, and 1 stop bit. For more information, call 212-705-7305 and ask for the Author's Guide.

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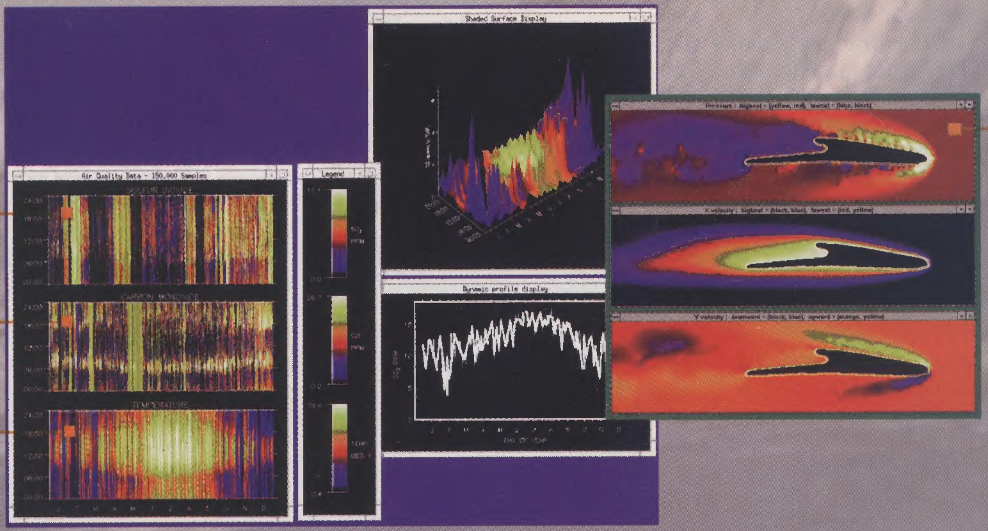

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EV watch

Northeast states tilt toward California

Electric vehicles got a strong boost on Feb. 1 from the Ozone Transport Commission (OTC), which voted to recommend that its low-emission-vehicle (LEV) program be set up by the Federal Environmental Protection Agency (EPA) in 12 states and the District of Columbia. By so doing, the commission has forced the agency to initiate a public review of the recommendation. The commission was created by the Clean Air Act Amendments of 1990 to coordinate the regional development of control plans for ground level ozone in the Northeast and Mid-Atlantic states.

In brief, the LEV program requires that, starting with the 1999 model year, each motor vehicle manufacturer must see to it that, as a group, all the passenger cars and light-duty trucks it sells within the Ozone Transport Region meet the standard for average fleet emissions specified by the California Air Resources Board. Unlike California, which mandates the composition of fleets, the commission's program just specifies a fleet average level for emissions; it allows manufacturers to compose their fleets as they choose from among vehicles in five classes categorized on the basis of their emission levels—from relatively high (California Tier 1) to zero-emission—just so long as the fleet average emissions goal is met.

Officially, then, the Ozone Transport Commission's program does not mandate the manufacture or sale of electric or hybrid electric vehicles. In practice, however, according to Sheila Lynch, executive director of the Northeast Alternative Vehicle Consortium in Boston, there is only way that the requirement for tropospheric ozone can be met—by having some zero-emission vehicles, which in effect, means electrics.

The American Automobile Manufacturers Association would seem to agree. In its response to the commission's action, it said, "The OTC proposal appears to be the California standards simply under a different name."

Commenting on the commission's vote, Timothy R.E. Keeney, chairman of its OTC LEV Committee, and commissioner of the Connecticut Department of Environmental Protection, held out even more hope for EVs. "While this proposal does not establish a zero-emission vehicle sales mandate, it does envision that [zero-emission] and other advanced clean vehicle technology, like electric cars, will not be left behind on the shelf."

Interestingly, the ozone commission's program adopts California's emissions standards without mandating its reformulated gasoline standards anywhere in the Ozone Transport Region. If anything, that combination of action and inaction would seem to strengthen the case for EVs. Cars powered by internal combustion engines will, after all, be harder pressed to meet the emissions requirements with conventional fuel than they would be if they could count on a supply of reformulated gasoline. In consequence, the need for zero-emission vehicles to lower fleet average emissions would appear to be all the greater.

Only four of the 13 members of the commission—Delaware, New Hampshire, New Jersey, and Virginia—voted against its action. Representatives from those states expressed doubts about the cost-effectiveness of the OTC LEV program.

Art students tackle EV design

Students will consider the issue of home EV charging stations and will attempt to come up with designs both for such stations and for compatible EVs in a program at the Art Center College of Design in Pasadena, Calif. The program is sponsored by the Electric Power Research Institute (EPRI) of Palo Alto, Calif. EPRI believes the program worthwhile, not only for the answers it may yield to a number of vexing questions, but also because it "...will help increase public awareness of the many benefits of electric transportation." So said Gary Purcell, project manager for EPRI's Transportation Program.

One issue the students will weigh will be the possibility of hands-free charging. EPRI calls it "autodocking." The lucky owner would simply park the vehicle in a garage at the end of the day without even thinking about charging. By morning, the car would have been fully charged, and sweeter yet, its interior would have been heated or cooled, as necessary.

The scheme will require that many problems be addressed. Among them: the cost of installing an autodocking system, compatibility with curbside and other public-access charging facilities, and safety—making sure that the system neither harms nor is harmed by children and pets.

In all likelihood, a successful autodocking system will be of the inductive variety—either of the high-frequency "insertion" type or the line-frequency "proximity" sort. Both use a split transformer in which the flux path, or core, is in two parts, with the primary wound around one and the secondary around the other.

The insertion type is exemplified by Hughes Power Systems Corp.'s Magne-Charge system, in which the part of the core with the primary winding slips inside the other through a slot on the vehicle. In the Hughes system, the primary is contained in a unit about the size and shape of a ping-pong paddle. To keep it small and light, the paddle excitation has a frequency in the high tens of kilohertz.

Proximity chargers, like those built by Inductran Corp., Albany, Calif., typically have a primary embedded in the floor or mounted on a wall stand, and a secondary mounted on the vehicle. To use them, the driver parks the vehicle so that the secondary is close to the primary. Many such systems are already in use for charging fork-lift trucks and automatically guided robotic vehicles in automated warehouses.

The students will formally present their results to EPRI executives on April 14. The models they build will be displayed at the 1994 National Electric Vehicle Infrastructure Conference, which will take place in Anaheim, Calif., from Dec. 5–7.

Formula Lightning to debut in Phoenix

When the fourth annual APS Electric 500 is run this month at the Phoenix International Raceway in Arizona, it will feature a new class of race cars, the Formula Lightning. Designed, built, and tested by the Phoenix-based Solar & Electric Racing Association (SERA), the Formula-style vehicle is believed to be the first modern competition test vehicle intended from the outset to be electrically powered.

According to SERA, its goal in creating the new class was to provide "...totally equal, complete rolling chassis less only batteries, motor, and controller so that companies can install their products and dramatically show their electric power and drive technologies on our nation's race courses." That goal is shared by the Goodyear Tire and Rubber Co., Akron, Ohio, which will supply tires to all Lightning race teams.

The Lightning chassis weighs about 450 kg and sells for US $25 000. According to SERA president Ernie Holden, veteran drivers of conventional racing cars are enthusiastic about the new class. In fact, two who have test-driven a prototype have agreed to drive production Lightnings in actual races.

Sponsored by the Arizona Public Service Co. and the U.S. Department of Energy, the APS Electric 500 is a series of races for five classes of entrants; it will run from March 18–20.

EDITOR: Michael J. Riezenman
CONSULTANT: Victor Wouk, Victor Wouk Associates

i860 DSP?

	ALACRON			Sonitech	Ariel	Spectrum
Model	FT200/2-AT	FT200-AT	AL860-AT	SP30-ISA-256	DSP96D	600-01515
Chip	Dual i860XP	i860XP	i860XR	TMS320C30	M96002	TMS320C40
Clock(MHz)	50	50	40	33	33	40
Memory	2 MB(d)	2 MB(d)	2 MB(d)	256 KB(s)	64 KB(s), 1 MB(d)	640 KB(s)
Mflops	200	100	80	33	50	40
IK FFT(usec)	320	547	730	2900	1100	1925
$/Mflop	**$56**	**$83**	**$84**	**$88**	**$94**	**$182**

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Memory: d = dram, s = sram. All product information provided by respective manufacturers in January 1993.

Books

Can technology save television?
Barrett Hazeltine

Why think about life after television? Because television will not survive once fiber optics reaches most homes and versatile computing chips are available to craft the bits and bytes brought in to fulfill users' desires. Or such is the claim made here.

Life After Television: The Coming Transformation of Media and American Life.
Gilder, George, W.W. Norton & Co., New York, 1993, 144 pp., $14.95.

With its few, spectrum-hogging channels and analog signals nearly impossible to store and process, television is bound to lose viewers to more flexible digital signals delivered through a fiber channel with essentially no bandwidth limitations. From the broad offerings on this channel, people will be able to select programs of special interest to them, rather than accept the "lowest common denominator" fare now shown on commercial TV.

Digital transmission will mean images can be stored and manipulated, permitting enhanced motion-compensation effects for sports events, truer color fidelity for travelogs, and a choice of cameras for such spectacles as presidential inaugurations and Super Bowls. The viewer will be in control, not the producer.

The argument goes as follows: when electronics was expensive and viewers were few, it made sense to have simple receivers, with program content and the broadcast method decided at the transmitter. Technology and economics dictated the use of analog-radio transmission. But simple TV receivers and analog transmission squander the radio spectrum on relatively few channels, necessitating the production of programs perceived as having the widest appeal. Such programs have been criticized as being culturally and morally degrading and for turning the viewer into a passive recipient. The paucity of channels, moreover, allowed few opportunities for creative expression and so impoverished both artists and viewers.

New technologies—fiber optics and digital circuitry—have now removed the historical constraints, making possible a greater variety of programming and the ability to use that variety at the receiver—and at reasonable cost. Gilder concludes by insisting that people will opt for their (mostly) more enlightened special interests when they can, rather than settle for the puerile or insipid offerings intended for a mass market. A wide range of opportunities therefore enriches their lives.

The parallel given is the demise or diminution of the general-interest magazines—*Collier's, Life, Look,* and *The Saturday Evening Post*—and the proliferation of specialized magazines. Other examples could be fast food chains, which have been forced to expand their menus, or automated teller machines, which have given customers more control. Gilder's long explanations of the new

technologies, though, are obviously aimed at people less familiar with communication technology than nearly all the readers of this magazine.

A case study detailing the implications of letting the user decide incorporates a new twist on commercial databases. Present-day systems are expensive to use, with about 90 percent of the cost being telephone line charges, much of which is incurred searching for, rather than transmitting, the desired information. A more sensible approach, when communication capacity is nearly free and switching can be done cheaply at the user's personal computer, would be to send the whole database on the fiber channel for the user to manipulate at will. The software would keep track of what information was actually extracted, and the user would pay for that, rather than for the time spent on the terminal.

Such a system is being developed by a start-up company, Cryptologics, headed by Peter Sprague, chairman of National Semiconductor Corp. In fact, most commercial applications of such a system probably would not require the fiber channel, as users could simply order a compact disc for delivery overnight.

If the technology is more or less in place for "telecomputing," the expected coalescence of television and computing, then why are we still waiting for it? In three words: the political system, according to Gilder. The main problem is the regulatory constraints on the Bell Operating Companies. In the United States, only the Baby Bells have the cash and the demand for fiber that will allow domestic producers, including AT&T Co., to build capacity and roll down the learning curve faster than Japanese companies. The Baby Bells, however, must justify their investments to state regulators, are excluded from information-based businesses, and cannot purchase from AT&T.

Furthermore, U.S. technological strength historically has been based largely on the successes of entrepreneurs. However, they have been hindered by present economic conditions—tax-based disincentives for investors in the United States to take risks and the low value of the U.S. dollar. The upshot has been that non-U.S. investors are coming to dominate venture capital for computer-related start-ups.

The weakest aspect of Gilder's argument concerns people, not technology. A sophisticated digital computer and display will certainly cost more and require more effort to use than the familiar analog receiver. The unanswered question is, what will viewers want or use? Or, more to the point, how soon will the technology be sufficiently inexpensive and user friendly to create a significant demand? As Gilder points out: "The real choice today is between personal computing and consumer electronics...." Many people would like to know which will be chosen.

As noted earlier, the intended reader is probably not the typical *IEEE Spectrum* subscriber—who may very well have been part of the technological advances Gilder writes about. In fact, the technical explanations given may put off some engineers.

The message is aimed at policy makers, either in companies or in government. To industrial leaders, the advice is to prepare for a digital world connected by fiber optics. Gilder refers to the well-known prophecy of Nicholas Negroponte of the Massachusetts Institute of Technology: TV will come through the wide band of fiber, and voice, through the flexibility offered by the air; and the user will expect much more control over what he or she views. To government leaders, the advice is to liberate the Baby Bells.

This is an interesting and engaging book. Nearly all readers will be provoked into thinking about what TV viewers want and will pay for, and how such individual decisions will influence our national culture.

Barrett Hazeltine is professor of engineering at Brown University in Providence, R.I. He has been active in the New Liberal Arts Program of the Alfred P. Sloan Foundation, which is concerned with the

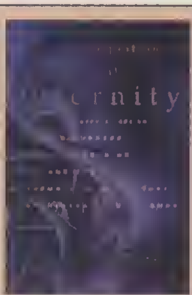
teaching of technology to students outside engineering. His teaching and research interests include the influence of technological choices on economic, political, and societal issues.

From here to eternity

Reuben Hersh

By chance, the same day I read this book, I also had picked up Lucretius' *De Rerum Naturae* (On the Nature of Things). Lucretius was a great poet who undertook to explain in verse everything under the sun, in accordance with the teaching of Epicurus. "What you see, hear, smell, taste, and touch is all there is, and it's exactly what it seems to be," he wrote.

Equations of Eternity: Speculations on Consciousness, Meaning, and the Mathematical Rules that Orchestrate the Cosmos. *Darling, David, Hyperion, New York, 1993, 190 pp., $19.95.*



Darling writes prose, but what he has undertaken is even more ambitious than Lucretius' aim. In all seriousness, he has set out to present the history of the universe, including mind and man, from the formation of planet Earth to the end of time! The book is a stirring work of prophecy, wearing a mask of science. It is readable and, in places, well written.

Philosophically, it is an incoherent mix of scientism (the universe to the end of time is forecast by 1990s' physics and cosmology, with a heavy dose of Kiplingesque triumphalism) and extreme empiricism ("Everything—the 'outside' world, your body, and, curiously enough, the very substance of your brain—is part of the experience that the brain creates.... When we look at a clock, a Geiger counter, we are watching only a subjective mental model fabricated within our brains."). Darling does not notice the incongruity between total confidence in theories we learn from telescopes and cyclotrons and skepticism that the chair he's sitting in is a chair or that the sky is blue. Lucretius at least kept his epicureanism straight.

In early chapters Darling tells stories about the "two brains" each of us has, and the origin and prehistory of *Homo sapiens*, which kindness will judge as myth, not science. The excitement comes in the remote, very remote, and extremely remote future.

"Theory suggests there are possible pathways through a spinning black hole that avoid any dangerous singularities and that travel instead along a space-time tunnel known as a wormhole," Darling writes. "The far end of the wormhole, astonishingly, may lie millions or billions of light-years away and be displaced by huge periods of time from the entrance...."

Darling then imagines a growing network of such wormhole pairs linking star systems and galaxies. He sees them as the equivalent of freeways, which would link "major objects such as galaxy clusters, while branch lines radiated out from the main terminals within a cluster to individual galaxies and then to individual stars. The likelihood is that we would have to construct all of this network from scratch, since the chances of natural black holes and wormholes being in handy locations is not very great."

Darling goes on to the possibility of creating entirely new, viable universes. "Essentially this would involve setting up the desired initial state of the new universe inside a wormhole, just as we can prepare, say, a primordial planetary atmosphere in laboratories today... Then the ends of the wormhole would be pinched off to produce a completely separate region of space-time," he continues. "The disconnected wormhole—now a new universe, or 'babyverse' in its own right—would subsequently evolve from the initial state we prescribed."

Darling argues that this evolution could involve something like "the Big Bang, which started our own universe, followed by a lengthy period of rapid expansion...we would free the infant cosmos to develop at a rate entirely outside our own time stream. It might, for instance, grow to be billions of light-years across in just a few minutes or hours as measured by our own clocks."

A space-time link with the babyverse would have to be reestablished, requiring us to compute its whereabouts in hyperspace relative to our own cosmos.

"In time, we might even discover how to prime a babyverse so that it went on to develop advanced life-forms," Darling suggests. "Through a subsequent space-time link, we could then establish communication with any intelligent inhabitants and let them know that we were their makers—in effect, their god. Perhaps, knowing how the trick was done, they would go on to spawn their own, third-generation universes. Or—a disturbing thought—perhaps all this has happened before, and in truth, our cosmos is someone else's babyverse."

Sadly, though, we never are shown the "equations of eternity" he mentions in his title. I would have liked to learn more about some of the remarkable scientific facts and quotations that Darling presents, but there is no bibliography, no footnotes. Occasionally, too, authors are mentioned without a journal name or year.

Reuben Hersh is professor of mathematics at the University of New Mexico in Albuquerque. He is coauthor of Descartes' Dream: The World According to Mathematics *(Harcourt Brace Jovanovich, New York, 1986). He has taught at Stanford University and was a visiting scholar at the Center for Research and Advanced Studies in Mexico City.*

EDITOR: Glenn Zorpette

Recent books

Expert Systems in Business and Finance: Issues and Applications. *Watkins, Paul R.*, and *Eliot, Lance B.*, John Wiley & Sons, New York, 1993, 367 pp., $49.95.

Effective Employee Orientation. *Jerris, Linda A.*, American Management Association, New York, 1993, 102 pp., $10.95.

User Interface Software. *Bass, Len,* and *Dewan, Prasun*, John Wiley & Sons, New York, 1993, 201 pp., $38.95.

Untangling Organizational Gridlock: Strategies for Building a Customer Focus. *Bechtell, Michele L.*, Amacom, New York, 1993, 347 pp., $27.95.

Abstract Data Types in Standard ML. *Harrison, Rachel*, John Wiley & Sons, New York, 1993, 212 pp., $44.95.

Everyday Heroes of the Quality Movement: From Taylor to Deming—The Journey to Higher Productivity. *Gluckman, Perry,* and *Roome, Diana Reynolds*, Dorset House, New York, 1993, 195 pp., $22.75.

The Peter Norton PC Programmer's Bible. *Norton, Peter, et al.*, Microsoft Press, Redmond, Wash., 1993, 632 pp., $29.95.

Computational Electromagnetics. *Umashankar, Korada*, Artech House, Norwood, Mass., 1993, 717 pp., $88.

Fundamentals of Electronic Imaging Systems: Some Aspects of Image Processing, 3rd edition. *Schreiber, W.F.*, Springer-Verlag, Newark, N.J., 1993, 332 pp., $54.

Incompressible Computational Fluid Dynamics: Trends and Advances. *Gunzburger, M.*, and *Nicolaides, R.*, Cambridge University Press, New York, 1993, 481 pp., $59.95.

Chemical Searching on an Array Processor. *Wilson, Terence,* John Wiley & Sons, New York, 1993, 197 pp., $115.

Computer Words You Gotta Know! *Freedman, Alan*, Amacom, New York, 1993, 174 pp., $12.95.

Engineering Electromagnetism., *Fuller, Baden A.J.*, John Wiley & Sons, New York, 1993, 294 pp., $37.95.

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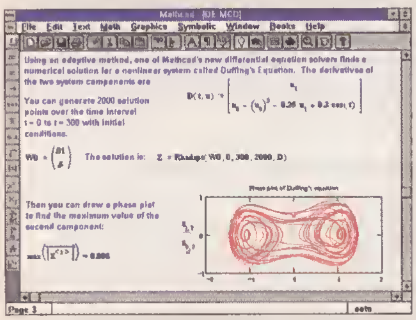

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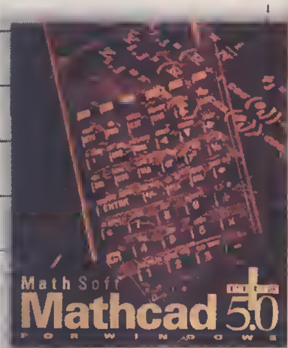

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Circle No. 12

Calendar

Meetings, Conferences, and Conventions

MARCH

Multi-chip Module Conference (ED); March 15–18; The Cocoanut Grove, Santa Cruz, Calif.; David P. LaPotin, IBM Thomas J. Watson Research Center, Box 218, Yorktown Heights, NY 10598; 914-945-2586; fax, 914-945-4469.

Networks for Personal Communications—NPC '94 (NJ Coast); March 16–18; Ocean Place Hilton, Long Branch, N.J.; Vijay K. Varma, Bellcore, 3X-325, 331 Newman Springs Rd., Red Bank, NJ 07701-7040; 908-758-2811; fax, 908-758-4371.

20th Northeast Bioengineering Conference (EMB); March 17–18; Western New England College, Springfield, Mass.; James V. Masi, Department of Electrical Engineering, Western New England College, Springfield, MA 01119; 413-782-1344; fax, 413-782-1746.

International Conference on Expert Systems for Development (C); March 18–21; Asian Institute of Technology, Bangkok, Thailand; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

26th Southeastern Symposium on System Theory (C, Columbus Section); March 20–22; Stocker Center, Ohio University, Athens; Dennis Irwin, Department of Electrical and Computer Engineering, Ohio University, Athens, OH 45701; 614-593-1922; fax, 614-593-0007.

International Systems Test and Diagnosis Workshop (C); March 20–24; Marriott Hotel, Annapolis, Md.; Colin Maunder, BT Laboratories, Martlesham Heath, Ipswich 1PS 7RE, United Kingdom; (44+473) 642 706; fax, (44+473) 642 459; e-mail; w.r.simpson@mcimail.com.

Second International Workshop on Configurable Distributed Systems (C); March 21–23; Carnegie Mellon University, Pittsburgh; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Capacitor and Resistor Technology Symposium (CHMT); March 21–24; Jupiter Beach Resort Hotel, Jupiter, Fla.; Clay Hamiter, Components Technology Institute Inc., 904 Bob Wallace Ave., Suite 117, Huntsville, AL 35801; 205-536-1304; fax, 205-539-8477.

International Conference on Control '94 (UKRI Section); March 21–24; University of Warwick, Coventry, Britain; Louise Bousfield, Conference Organizer, IEE Conference Services, Savoy Place, London WC4R OBL, Britain; (44+71) 344 5467; fax, (44+71) 497 3633.

International Conference on Microelectronic Test Structures (ED); March 22–24; Catamaran Resort Hotel, San Diego, Calif.; Sandra Grawet, All About Meetings Inc., 2301 Artesia Blvd., Suite 12–101, Redondo Beach, CA 90278; 310-371-3438; fax, 310-371-1567.

Joint Railroad Conference (VT); March 22–24; Palmer House Hilton, Chicago; W. Robert Moore, Parsons De Leuw Inc., c/o Chicago Circulator Project, 125 W. Wacker Dr., Chicago, IL; 312-357-2221.

Sixth International Conference on Indium Phosphide and Related Materials—IPRM (ED, LEO); March 28–31; Red Lion Resort, Santa Barbara, Calif.; Susan Evans, IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3896; fax, 908-562-1571.

Symposium on Electromagnetic Compatibility (SCV/EMCC); March 29–30; Santa Clara Convention Center, California; David M. Hanttula, IEEE SCV EMC '94, Box 2102, Cupertino, CA 95015; 415-390-1071; fax, 415-962-9439.

Data Compression Conference—DCC '94 (C); March 29–31; Cliff Lodge, Snowbird, Utah; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

National Radar Conference (AES, Atlanta Section); March 29–31; Holiday Inn Crowne Plaza Ravinia, Atlanta, Ga.; Robert N. Trebits, Georgia Tech Research Institute, 7220 Richardson Rd., Smyrna, GA 30080; 404-528-7769; fax, 404-528-7883.

Southcon '94 (Region 3, Florida Council); March 29–31; Orange County Convention/Civic Center, Orlando, Fla.; JoAnn Lindberg, ECM, 8110 Airport Blvd., Los Angeles, CA 90045; 800-877-2668; fax, 310-641-5117.

(Continued on p. 71)

Speakout

In academe's grungy groves

Analyzing the shortcomings of the U.S. engineering education system is a growth industry. There have been numerous editorials, commission reports, commentaries, and complaints on the subject. Blame has been placed on every party in sight, including the secondary school system, television, uninvolved parents, high school science programs and teachers, legislators, high equipment cost, obsolete laboratories, textbooks, and curricula. But has anyone taken a careful look at the environment within the university and its effect on the engineering faculty?

Here are some anecdotal reports to start such an examination. I have intentionally limited them to a factual recounting of events as they actually occurred; readers are left to draw their own conclusions without being influenced by my biases (any more than is implicit in the choice of the anecdotes).

• In the August 1990 issue of the *IEEE Electron Device Letters*, editor John Brews reported the detection of the simultaneous publication in two places of a paper by U.S. academics—in his own journal and in *Applied Physics Letters* a few months earlier. The same issue, carrying the editor's reprimand and call for vigil, contains only one other paper by U.S. academics. That paper, too, virtually duplicates one published a month earlier in the July 5, 1990, issue of *Electronics Letters*.

• The editor of an *IEEE Transactions* sent me a manuscript to review. It was difficult for me to determine if the technical content of the manuscript merited publication, because the writing was appalling: it contained dozens of spelling errors, grammatical mistakes, undefined terms, incomplete sentences, citation errors, and inappropriate choices of terms and words. The paper had five authors, three of whom are established professors at as many well-known U.S. research universities. The first author was a foreign student at one of those institutions.

• A few years ago, I interviewed an applicant for a job who had just finished the work for a doctorate in engineering at a well-known university. The candidate had an exceptionally narrow focus and no background, because "none was needed," in anything other than the topic of the dissertation. The explanation offered was that the doctoral work was done in a hurry on a "contract" basis: the thesis supervisor needed a device with a particular structure to meet his commitments to some research sponsors, and the student was promised a doctorate upon completion of that device.

• A friend at a state university recently recounted that his engineering college had hired an established researcher as a faculty member, but that this individual had left after only two years. The narrator lamented the loss of his department's investment, pointing out that the person had been assigned to teach exactly one course in these two years.

• Some time ago I dined with a senior faculty member from an engineering college at a large state university in the southwestern United States, who was recruiting assistant professors for his department. During the meal, he revealed the position of his department on good teaching: "The teaching has to be good enough that no complaints from students reach the dean. Beyond that, if a faculty member spends more than the minimum effort, and tries to be an excellent teacher, in our view he does so for his own enjoyment, and should not expect the department to reward him for pursuing his hobby."

• A heated and loud conversation between an undergraduate student and a professor (mildly well-known in his field of research), overheard by me in the hallway at a state university, reached this climax:

Student: "It is your duty—you are paid by our tax dollars."

Professor: "No, I'm not—I bring in more research dollars than the university pays me."

• As is well known, faculty openings in engineering colleges tend to be dominated by the so-called "junior" positions (assistant professorships, especially for recent graduates). A survey of the announcements for the "senior" positions shows that they mention the aggressive pursuit of research funding and/or sponsorship more than four times as often as excellence in teaching.

• Some years ago, during a visit to a campus clamoring for more space and money for engineering laboratories, I was surprised to find not one but two well-equipped laboratories devoted to experimental research in the same equipment-intensive and expensive field of work. Their independent existence stemmed from the fact that they belonged to two professors who, it was explained to me, "get their own funding."

Madhu S. Gupta

An expatriate from academia, Madhu S. Gupta was a faculty member for 15 years and still enjoys teaching occasionally at the University of California at Los Angeles. He is a senior member of the technical staff at Hughes Aircraft Co., Torrance, Calif.

Smart cars may not be smart

Much is being made of "smart" cars navigating automatically on intelligent vehicle highway systems. The assumption is that

The Apple Report On PowerPC

Macintosh Compatibility and Upgrades

PowerPC will easily outrun Intel's acclaimed Pentium microprocessor, but will do so at a fraction of the cost.

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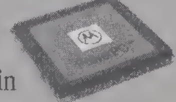
Macintosh with PowerPC will bring a new level of performance to your desktop. Yet you can continue to work with all your current files, applications and peripherals in exactly the same way you work with them now. It's compatible with all the Macintosh computers and software you already own, protecting any investment you've already made with Apple.® There's no retraining. No rethinking. No re- anything.



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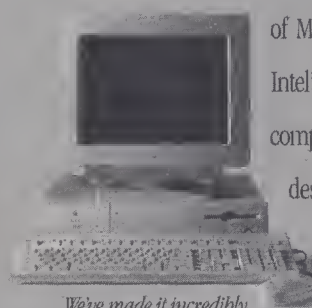

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Sit down and work on a Macintosh with PowerPC, and you'll quickly find that it's still a Macintosh. As easy to use as ever. As forgiving as ever. As human as ever.

Apple has already announced plans to ship upgrade products concurrently with the initial introduction of Macintosh with PowerPC systems.

Upgrades have been announced for the Macintosh Quadra® 610, 650, 660AV, 700, 800, 840AV, 900 and 950, the Macintosh Centris™ 610 and 650, the Macintosh IIvx and the popular Macintosh Performa® 600. More will follow.

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Speakout

progress in controls, communications, and computers has made technical solutions practical for the problem of highway congestion.

This hope may not always be realized by the Intelligent Vehicle Highway System (IVHS) programs being investigated in the United States. Take the case of the Advanced Traffic Information System (ATIS), which would help motorists avoid traffic tie-ups by suggesting less crowded routes. When alternatives are possible, ATIS may indeed reduce traffic congestion. But when all bridges and tunnels into, for example, the island of Manhattan in New York City are clogged, ATIS may elicit less relief than frustration.

In the most controversial project, vehicles would be guided automatically while traveling at high speed in a special lane, where a control system could take over and free the drivers to read, write, or even sleep.

Many objectives of the IVHS are also part of the ambitious European research project Prometheus, launched in 1987. In Germany, the "autonomous vehicle" is called Automatische Fahrzeugführung auf Autobahnen. The English translation is "automatic vehicle guidance on freeways" (AVGF).

An independent feasibility analysis of the autonomous vehicle, of which few outside Germany may be aware, was conducted by the Institut für Strassenbau und Eisenbahnwesen (Roads and Railways) of the Technical University in Karlsruhe. Professor Hiersche there directed the investigation and published a five-page report on the disadvantages of an automatic guidance system on German freeways (*Strasse und Autobahn*, Issue 10, October 1989, p. 379).

Highlights of Hiersche's conclusions were:
- German freeways are not built and cannot be modified economically for an automatic vehicle guidance system. Modifying bridges and tunnels is almost impossible.
- Automatic guidance must be abandoned on days when special lanes are needed for any reason, such as detours or repair work.
- Bad weather like rain, snow, ice, fog, and high winds may reduce the safety margin for automatic guidance to nothing.
- Entering and leaving the automatic guidance system—with cars zooming along 5 meters apart at speeds reaching 120 km/h—is a highly likely source of accidents.

Hiersche concluded that the German AVGF system failed the feasibility test completely. I doubt that an autonomous vehicle guidance system in the United States would fare any better.

High technology is not the best way to attack highway congestion. With the right mix of cars, vans, and buses, it should be possible to double or triple the people-moving capacity of a highway.

Wilhelm H. von Aulock
Munich, Germany

Recent books

(Continued from p. 12)

Engineering Economic Analysis: An Introduction. *Lindeburg, Michael R.*, Professional Publications, Belmont, Calif., 1993, 231 pp., $15.95.

Lateral Electromagnetic Waves: Theory and Applications to Communications, Geophysical Exploration, and Remote Sensing. *King, Ronald W.P., et al.*, Springer-Verlag, Newark, N.J., 1993, 746 pp., $79.

Dead Reckoning: Calculating Without Instruments. *Doerfler, Ronald W.*, Gulf Publishing, Houston, Texas, 1993, 182 pp., $17.95.

Electron Correlations in Molecules and Solids, 2nd edition. *Fulde, Peter*, Springer-Verlag, Newark, N.J., 1993, 422 pp., $52.

Mobile Communications in the US and Europe: Regulation, Technology, and Markets. *Paetsch, Michael*, Artech House, Norwood, Mass., 1993, 417 pp., $89.

Coding Theory, Design Theory, Group Theory: Proceedings of the Marshall Hall Conference. *Jungnickel, D.*, and *Vanstone, S.A.*, John Wiley & Sons, New York, 1993, 299 pp., $86.

Radiosity and Realistic Image Synthesis. *Cohen, Michael F.*, and *Wallace, John R.*, Academic Press, Cambridge, Mass., 1993, 381 pp., $49.95.

Germanate Glasses: Structure, Spectroscopy, and Properties. *Margaryan, Michael A. Piliavin*, Artech Press, Norwood, Mass., 1993, 181 pp., $72.

Software Engineering Productivity Handbook. *Keyes, Jessica*, McGraw-Hill, New York, 1993, 651 pp., $54.50.

Integrated Dpto-Electronics: Waveguide Dptics Photonics Semiconductors. *Ebeling, K.J.*, Springer-Verlag, Newark, N.J., 1993, 537 pp., $59.

Fiber Dptics, 2nd edition. *Hoss, Robert J.*, and *Lacy, Edward A.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 290 pp., $45.

Modern Image Processing: Warping, Morphing, and Classical Techniques. *Watkins, Christopher, et al.*, Academic Press, Cambridge, Mass., 1993, 234 pp., $49.95.

Waveguide Components for Antenna Feed Systems: Theory and CAD. *Uher, Jaroslaw, et al.*, Artech House, Norwood, Mass., 1993, 456 pp., $99.

UNIX Internetworking. *Pabrai, Uday O.*, Artech Press, Norwood, Mass., 1993, 197 pp., $65.

Visual Basic Workshop. *Craig, John Clark*, Microsoft Press, Redmond, Wash., 1993, 504 pp., $39.95.

CAD for Control Systems. *Linkens, Derek A.*, Marcel Dekker, New York, 1993, 584 pp., $150.

Quick Reference to Computer Graphics Terms. *Stevens, Roger T.*, Academic Press, Cambridge, Mass., 1993, 237 pp., $29.95.

Secure Data Networking. *Purser, Michael*, Artech Press, Norwood, Mass., 1993, 241 pp., $66.

The Dynamics of the Computer Industry. *Touma, Walid Rachid*, Kluwer Academic, Boston, 1993, 213 pp., $69.95.

Engineering Problem Solving with Matlab. *Etter, D.M.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 433 pp., $39.

The Multimedia Production Handbook for the PC, Macintosh, and Amiga. *Yager, Tom*, Academic Press, Cambridge, Mass., 1993, 382 pp., $35.95.


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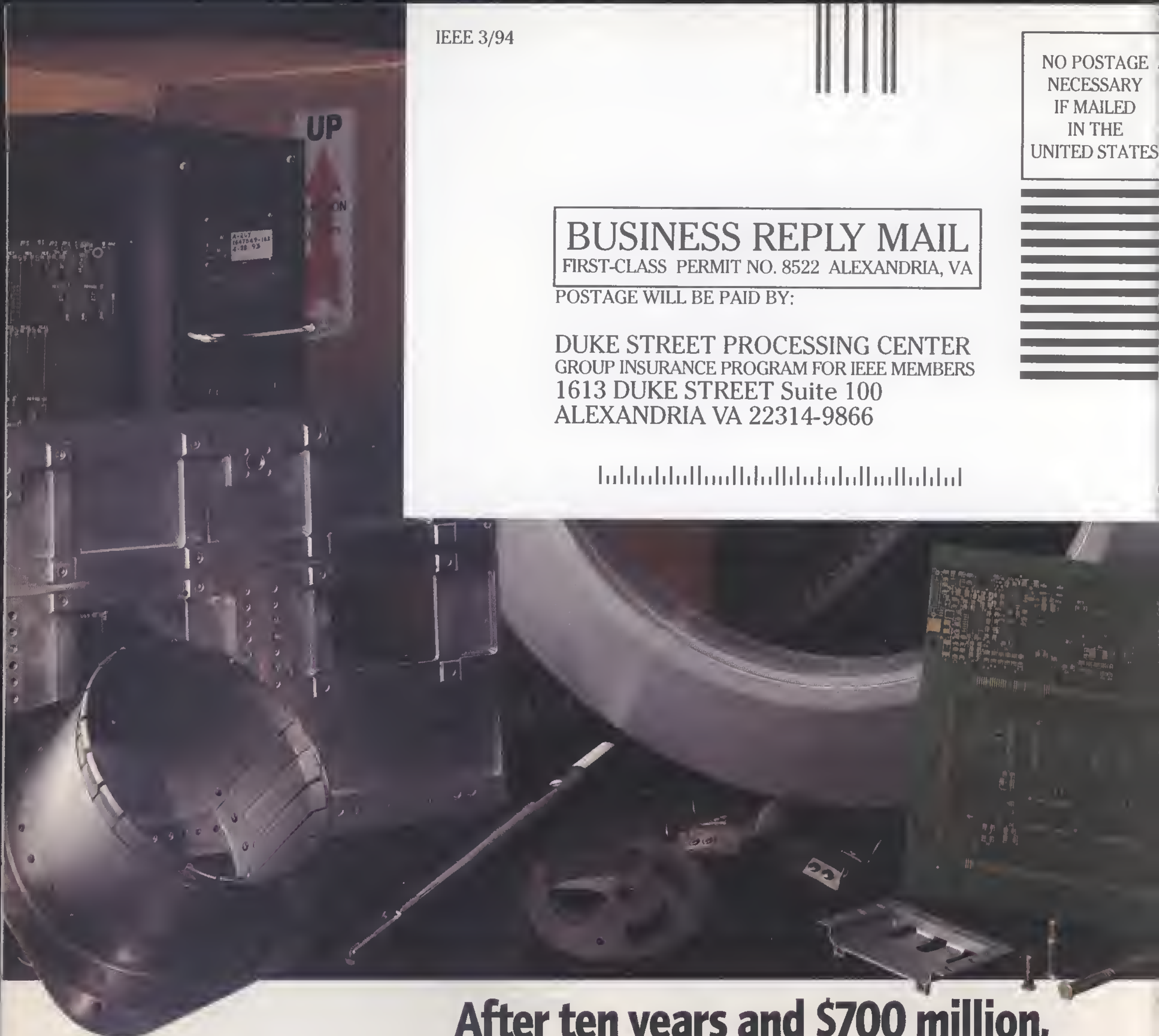
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Washington watch

Technology R&D boosted in proposed budget

Engineers and scientists fared comparatively well in the 1995 Federal budget proposed in February by President Clinton. The austere spending plan asks Congress to raise R&D support by some 3 percent to $73 billion. John H. Gibbons, the President's science and technology advisor, said not all the desired programs were supported and that hard-won increases had "to come at the cost of other things."

Among big winners were the Commerce Department [see story below] where R&D would see double-digit growth. The National Science Foundation would rise nearly 10 percent to $2.2 billion. The National Institutes of Health would increase nearly 5 percent to $11 billion. Government-wide support of communications and computing research would jump 23 percent to $1.2 billion; environmental technology would rise 11 percent to $0.5 billion; and global change research gain 24 percent to reach $1.8 billion.

Not all were ecstatic with the R&D proposed increase, however. Expressed as a percentage of gross domestic product, science spending in 1995 would be less than any year since 1958, noted Representative George E. Brown Jr. (D-Calif.), chairman of the House Science, Space, and Technology Committee.

Space agency shifts

Among the R&D losers in the proposed budget was the National Aeronautics and Space Administration (NASA). The space agency would see its budget shrink for the second straight year, this time by $250 million to $14.3 billion, with the possibility of further cuts by Congress. "This is it. We can't get any closer to the bone," said NASA chief Daniel S. Goldin in a prepared statement regarding the budget announcement.

The international space station would receive its maximum allotment of $2.1 billion. The shuttle program would see a 6 percent drop to $3.3 billion. And plans for an advanced solid rocket booster and improvements to allow one of the shuttles to stay in orbit longer were canceled.

The budget continues a shift of funds away from manned flight in favor of unmanned operations. The Cassini mission to Saturn and the Advanced Astrophysics Facility would remain, and a new Mars Surveyor program calls for $78 million to develop a small orbiter to launch on a Delta rocket in 1996. It would carry about half the scientific payload of the ill-fated Mars Observer program that disappeared last August. Support for Mission to Planet Earth, an earth observation project, would rise 20 percent to $1.2 billion.

Smiles in commerce

Civilian technology development was the big beneficiary of President Clinton's 1995 budget proposal, released in February. "I'm one of the few members of the cabinet who has a smile on his face today," said Secretary of Commerce Ronald Brown, as he unveiled his budget. Overall, the Commerce Department would get an 18 percent rise to US $4.2 billion, about $1 billion more than the final Bush budget two years ago.

Washington watch

The biggest proposed boost is for the National Institute of Standards and Technology (NIST). That budget would rise to $935 million, up from $381 million two years ago, largely because of the developing Advanced Technology Program (ATP). (NIST director Arati Prabhakar expects to announce the first ATP strategic program areas around April.) Also noteworthy is the expansion of the Malcolm Baldrige National Quality Awards to the health and education communities.

Additional budget boosts would give $11 million to strengthen analytic capabilities for technology policy and $18 million to support the electronic dissemination of items in the National Technical Information Service. Already this year's proposed $1.5 trillion budget is available on CD ROM, which may be more convenient than the usual 4-kg multivolume phonebook format also offered.

U.S.-Japan mixer

Thirty U.S. manufacturing engineers will spend a year at Japanese companies under a fellowship program sponsored by the U.S. Department of Commerce and Japan's Ministry of International Trade and Industry. The engineers were feted in January at a send-off luncheon in Washington, D.C. Among the U.S. companies participating in the program are General Motors Corp., which is sending four engineers, and Ford Motor Co. and Motorola Inc., with three engineers each. The host Japanese companies include Hitachi, Honda, Matsushita Electric Industries, Nissan, Sony, Toshiba, and Toyota. More information on the program is available from Amy Cammell, Society of Manufacturing Engineers, 313-271-1500.

Privacy needs protection

Two recent reports from the National Academy of Sciences in Washington, D.C., warn that advances in technologies and the increasing collection of data can jeopardize individuals' privacy.

Private Lives and Public Policies: Confidentiality and Accessibility of Government Statistics urges new legislation to protect all data collected by some 70 largely decentralized Federal agencies. The 274-page report recognizes that fear of risks to confidentiality could hinder the collection of data that contributes to the understanding of "significant economic and social problems."

The other report, *Health Data in the Information Age: Use, Disclosure, and Privacy,* also recommends that steps be taken to guard records that may contain personal medical information from insurance companies, pharmacies, and surveys. It suggests setting up individual health identification numbers, which would be separate and different from social security numbers, which are not protected by law as confidential. To learn more or to order these reports, call the National Academy Press at 800-624-6242.

Productive computers?

Engineers may take it for granted that computers boost their output. But service companies are not as positive about their bottom-line productivity in the Information Age. During the 1980s, banks, airlines, and other U.S. service companies spent more than $750 billion on hardware alone, and untold billions more on software. Conventional measures of productivity, however, reveal few benefits from such purchases. A panel from the National Research Council tried to unravel this paradox and said the focus should not be just on narrowly defined productivity of a service, but also on its overall performance. This includes new services and conveniences (like automated teller machines) as well as the capability of handling jobs of increased complexity (such as computerized reservation systems). The 270-page report is available from the Government Printing Office at 202-783-3238.

John A. Adam Washington Editor

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he United States must get irning their research into ucts. Their informal links to o be superseded by a firm) industrial partnerships, arles Vest, president of the Institute of Technology, in

must continue its role as a sic research, especially now e Federally funded laborato- t stopped conducting long- Vest said in an article in the 3 issue of *Challenges,* pub- nprofit Council on Competitiveness, Washington, D.C. He also called for "substantial" change in both engineering and management education. Engineering and business schools need to work together to promote a better understanding of team-

recruiting but also retaining greater numbers of women scientists and engineers than before.

The companies' initiatives have much in common—above all the active support of top management. Other elements include the

charter.

Women Scientists and Engineers Employed in Industry: Why So Few? is a 130-page paperback book that is available for US $29 plus shipping. *Contact: National Acad-*

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John A. Adam Washington Editor

Engineer at large

Wooing women engineers

In U.S. industry, there is only one woman for every seven or eight men in the scientific and engineering labor force. This disparity is due in part to the abnormal attrition rate for women pursuing careers in industry, which is double that for men and much higher than in other employment sectors, according to a report that was released in January by the National Research Council's Office of Scientific and Engineering Personnel (OSEP), Washington, D.C.

The report examines why women drop out in such numbers and describes how a half dozen companies—including Aerospace Corp., Alcoa, AT&T Bell Laboratories, Xerox Corporate Research and Technology, and a biotechnology company, Scios Nova—have sought to reverse the trend by not only recruiting but also retaining greater numbers of women scientists and engineers than before.

The companies' initiatives have much in common—above all the active support of top management. Other elements include the availability of flexible work schedules, part-time employment, and attention to family issues such as parental leave and day care. Clear, consistent criteria for promotion, as well as more opportunities for lateral transfers, were also shown to help women's career development and dissuade them from leaving a company.

The report is based on a conference organized by the OSEP's Committee on Women in Science and Engineering. Both the report and the conference were sponsored by the National Academy of Engineering, General Electric Foundation, and Battelle Pacific Northwest Laboratories. The National Research Council, the operating arm of the National Academy of Sciences and the National Academy of Engineering, is a private, nonprofit institution that provides independent advice on science and technology issues under the auspices of a congressional charter.

Women Scientists and Engineers Employed in Industry: Why So Few? is a 130-page paperback book that is available for US $29 plus shipping. *Contact: National Academy Press, 2101 Constitution Ave., N.W., Washington, DC 20418; 202-334-3313 or 800-624-6242.*

University-industry partners in earnest

Universities in the United States must get serious about turning their research into marketable products. Their informal links to industry need to be superseded by a firm commitment to industrial partnerships, according to Charles Vest, president of the Massachusetts Institute of Technology, in Cambridge.

Yet academia must continue its role as a resource for basic research, especially now that many of the Federally funded laboratories have all but stopped conducting long-term research, Vest said in an article in the December 1993 issue of *Challenges,* published by the nonprofit Council on Competitiveness, Washington, D.C. He also called for "substantial" change in both engineering and management education. Engineering and business schools need to work together to promote a better understanding of team-

Engineer at large

work and help students understand the effects of technology and economic policy on manufacturing decisions, he said.

Biotech head for science association

A champion of biotechnology research and its application to health, the environment, and the economy has been named president-elect of the American Association for the Advancement of Science (AAAS), Washington, D.C. Rita R. Colwell, president of the University of Maryland Biotechnology Institute, was to begin her three-year term with the AAAS on Feb. 24, right after the association's annual meeting in San Francisco.

"We've had 40 years of science dominated by physicists, space scientists, and engineers," commented Donald N. Langenberg, chancellor of the University of Maryland System. "I think it is particularly significant, in the era of genetic engineering and its powerful contributions to the world society, that the AAAS membership has chosen Dr. Colwell, a prominent life scientist, as its incoming president."

Colwell's research in ecology and the genetics of marine bacteria, viruses, and their animal and plant hosts has earned her honors worldwide. Following one year as president-elect, she will become president of the AAAS in 1995, and chair of the Board of Directors in 1996.

Engineering jobs pick up, maybe

Although the U.S. Bureau of Labor Statistics reported a decline in engineering unemployment in the third quarter of 1993, its numbers may be more rosy than real. The third quarter's rate was 3.8 percent, according to the bureau, down from a historic high of 4.5 percent in the previous quarter. Electrical engineering unemployment was somewhat lower at 3.5 percent.

The rate should remain flat for "several more quarters" owing to constant downsizing and layoffs, noted a recent article in *Impact*, a newsletter for leaders of IEEE-U.S. Activities' Professional Activities Committees for Engineers.

But these rates can be misleading, according to the article's author, Frank E. Lord, a member of the Career Activities Council. Engineers no longer collecting unemployment benefits or else working in nonengineering jobs are not counted. "If they were, I estimate that the percentages would be doubled, placing them nearer the general population figures," he concluded.

Meanwhile, at U.S. colleges, the number of engineering graduates rose in 1993. Over 65 000 bachelor's degrees were awarded—up about 2 percent from 1992 and the first increase since 1986. So said the Engineering Workforce Commission of the American Association of Engineering Societies, Washington, D.C.

Salvadori of ASCE given Hoover Medal

Mario Salvadori, honorary chairman of Weidlinger Associates, consulting engineers, received the Hoover Medal at the annual convention of the American Society of Civil Engineers (ASCE), held in Dallas in October.

The James Renwick professor emeritus of civil engineering and professor emeritus of architecture at Columbia University, New York City, Salvadori was interested in helping young people in the inner city master science and mathematics by studying the built-up environment around them. So he founded a nonprofit educational organization called the Salvadori Educational Center on the Built Environment.

The award commemorates the civic and humanitarian achievements of U.S. President Herbert Hoover, an honorary member of the ASCE. The Hoover Medal Board includes representatives of the IEEE and other engineering associations.

Alfred Rosenblatt

Reflections

What happened to numbers?

On a recent trip to Purdue University, the astronaut Neil Armstrong presented his alma mater with his old slide rule. Several of us other old alums looked wistfully at that aged wooden instrument, and it brought back shared memories of what it used to be like to be an engineering student.

Long before the word *nerd* was fashionable, engineers were maliciously identified by the long leather cases suspended from their belts. It was an "ever-ready" case, because you never knew when a number would be needed on the spur of the moment. A slide rule was my first purchase as a student, and at about $30, it was relatively expensive. Even though I had no idea at first how the thing worked, that slide rule was my most prized possession. In fact, unlike Armstrong, I still have mine. (Basically, there is no market for mine.)

I quickly realized that the key to being a good engineer was mastery of the slide rule. Thus I learned to carry temporary results from scale to scale on the rule, and I diligently strove to get that not-quite-achievable third decimal place. After all, numbers were all-important; they were what engineering was all about.

My slide rule was full of every number I could want, but of course not every number was a good one. Good numbers were the ones considered to be the correct answers to exam questions; the bad ones were everything else. It didn't matter how well you understood the subject matter—if you slipped with your slide rule, you failed. This was so important that, like everyone else, I learned to work out a quick number by hand, just to check the slide rule and be sure the decimal place was correct.

How times have come and gone since then! Now slide rules are found only in museums, except museums don't care about them, either. Electronic calculators came along and were exorbitantly expensive until something happened and they started appearing in cereal boxes. They didn't even make it to museums. Then personal computers conquered the universe, and now you can't exist as a student without a laptop. So what makes you think they're here to stay?

Meanwhile, Armstrong went to the moon, which is also hard to believe because that was back in 1969 before we had PCs. When you see the equipment that the astronauts used then, it looks hopelessly ancient. Armstrong's slide rule would not have been out of place. Today, of course, we have sophisticated computers, backed by millions of lines of mission software. We don't go to the moon anymore, though.

In fact, if I might digress for a moment, in these days of aborted countdowns, the moon landing was in retrospect an incredible feat. It is almost 25 years later, and it isn't clear to me that we could do it again. Moreover, the social impact of that event stands in contrast to the fractionalizing of television viewership that technology is inducing today.

Norm Bendell

Science fiction writers had, of course, predicted a moon landing for decades, but none of them had foreseen that the landing would be on live, worldwide television. In these days when we are rushing toward 1000-channel television and individualized video-on-demand, I often think that the singular moment in the history of television was July 29, 1969, when it brought the world together for one glorious, shared event. In fact, I told Armstrong that he was the only one who missed out on it. It was thoughtless of him to have been away on a business trip.

But back to numbers...That old slide rule made me remember the forgotten primacy of numbers. Not only have I not used the slide rule since I left school, but—and I know this sounds perverted or impossible—I've hardly needed a number in all these years. There, I've made a great confession! Of course, at income tax time I rummage around trying to find one of the calculators littering the backs of forgotten drawers, but other than that I seem to get along all right without them.

When I reflect on the improbability and unexpectedness of this numberless existence, I conclude that, as in many other matters, I was misled by the artificiality of the college classroom. Tests seem to beg for numbers, while life may not.

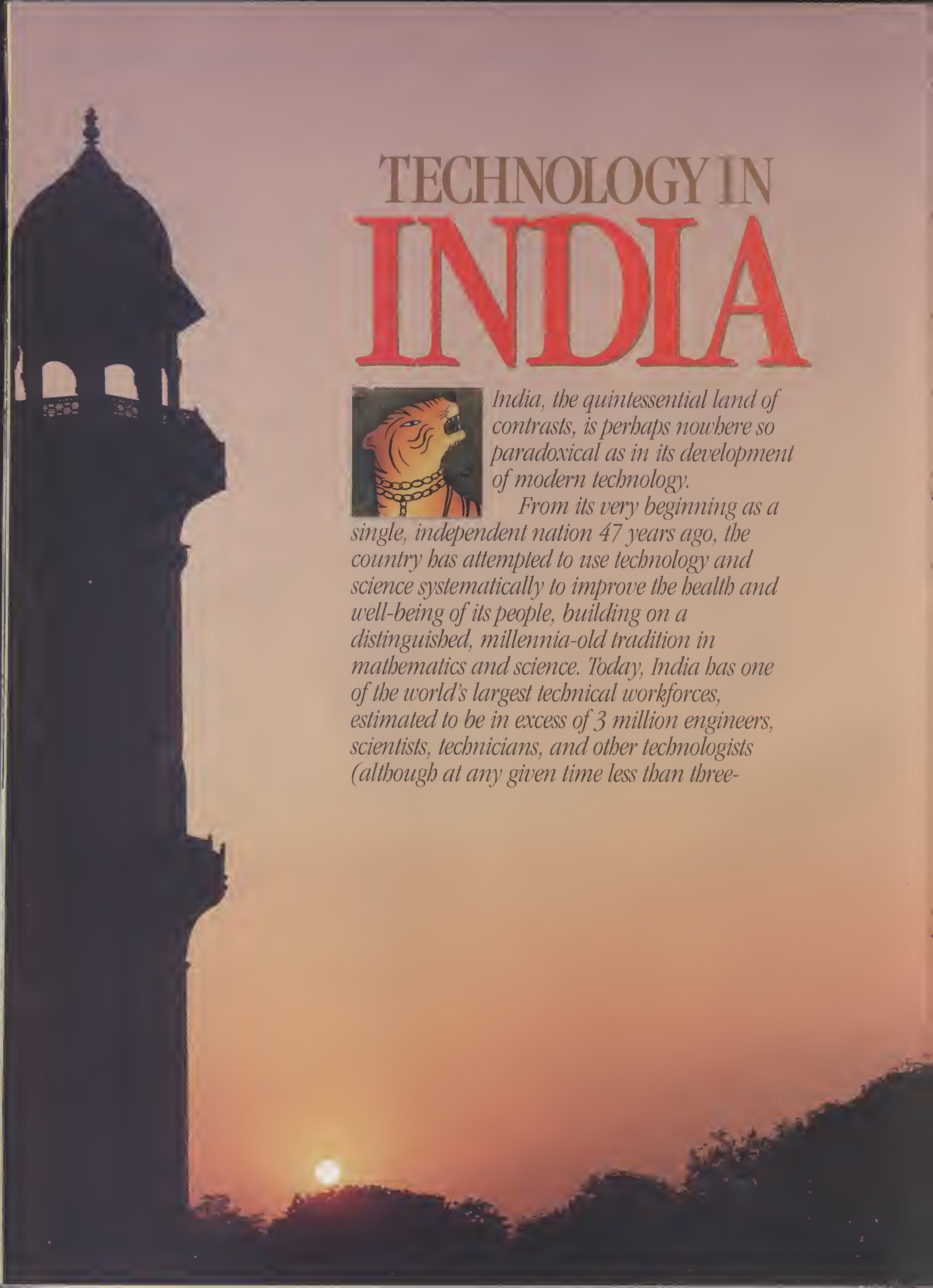
But times have changed, too; the world of engineering is now full of concepts, systems, and software. Numbers are kept somewhere in the backs of computers where people don't see them, and instead visualization programs display data and trends in an intuitive manner. I often think of Hamming's wonderful remark, "The purpose of computing is insight, not numbers."

I envy the students of today with computer simulations and tools like Mathematica. A focus on the numbers themselves often obscures conceptual intuition. And I imagine with jealousy how it will be in the future, when students will use artificial reality to explore and experience hands-on the conceptual world of mathematics and engineering. At the same time, I must admit that when you are asked to produce a number, you discover whether or not you really understand something. There is something hard-nosed and unequivocal about a number. "Put up or shut up," it says to you. Perhaps that is why numbers may be over-important in school.

In the numberless world of life-after-school, I usually find out whether I know something when I have to give a talk about it. I can hardly confess the number of times I have been in the midst of explaining something to an audience when I suddenly discover that I don't know what I'm talking about! I often wonder whether this happens to anyone else. All I can tell you is that when this realization occurs, something goes fuzzy inside me, and I get the sensation of being in the audience watching this jerk—me—losing all powers of articulation. Maybe someone should have asked me to produce a number. I could have done that in secret!

The computer tells me I have so far written 1012 words, which is just about my quota for this essay. So much for the thoughts and concepts—in the end a number rules supreme!

Robert W. Lucky



TECHNOLOGY IN INDIA

India, the quintessential land of contrasts, is perhaps nowhere so paradoxical as in its development of modern technology.

From its very beginning as a single, independent nation 47 years ago, the country has attempted to use technology and science systematically to improve the health and well-being of its people, building on a distinguished, millennia-old tradition in mathematics and science. Today, India has one of the world's largest technical workforces, estimated to be in excess of 3 million engineers, scientists, technicians, and other technologists (although at any given time less than three-

fourths of them have technical or scientific jobs). The best are a match for the best anywhere, as evidenced by the success of Indian expatriates the world over—an unambiguous testament to a select group of excellent technically oriented institutions of higher learning in India.

Indeed, in several strategically important areas—nuclear science and technology, satellite technologies, massively parallel computers, and certain industrial chemical processes—India's achievements are unmatched anywhere else in the developing world. So, too, is its effort to develop superconductors, a significant initiative encompassing both thin films and wires. And in scarcely half a dozen years, a number of aggressive, entrepreneurial Indian companies have been so successful in software consulting that no one can doubt now that India is home to some of the world's best expertise in Unix and several other operating systems.

Notwithstanding all this, India remains a poor and backward country, even by the standards of the developing world. The usual metrics are per-capita gross domestic product (GDP), exports, electricity use, density of telephones, literacy, infant mortality, and life expectancy, and by any of them, India trails far behind even its developing neighbors in Asia.

The sum total of India's exports in 1992 was a little under US $20 billion—or slightly more than China's balance-of-trade surplus with just the United States. India's per-capita GDP of roughly $350 (according to Indian government and World Bank figures) is about two-thirds of Indonesia's—in fact, only half when adjusted for purchasing power parity. Its per-capita electrical capacity of 330 kWh is a little over half of China's; and its eight telephones per 1000 people is less than *one-tenth* of the average in the developing world. Sewage goes untreated, and tap water, where available, remains undrinkable over vast areas of the country. In literacy, India ranks 109 out of the 127 nations tracked by the World Bank.

In short, over the last four decades, while most of east Asia was making great strides toward Western standards and comforts, India was being left far behind.

Largely because of this state of affairs, India is in the early stages of one of the most momentous transitions since its independence. With an increasing sense of urgency, the world's largest democracy is attempting to integrate itself into the global economy, which it believes offers the best, and perhaps only, chance of fundamental change.

In a slow and methodical program, interrupted by large-scale ethnic clashes and terrorist attacks (and at least one devastating earthquake), the rupee has been made convertible with other world currencies; tariffs on some imports have been reduced, foreign companies have been allowed to do business and compete for certain contracts (in telecommunications and electric generation, for example); and the permitted level of foreign direct investment in Indian companies has been increased. In general, Government interference with, and micro-management of, the affairs of business and commerce has been mitigated a bit. Still, this huge and incredibly diverse country—home to almost a sixth of the world's people—has a long way to go before it can be considered even a minor cog in the global machine.

As it strives for such a modest goal, India will undoubtedly become a model for other developing countries seeking

Glenn Zorpette

Glenn Zorpette Senior Associate Editor

R. Shanmugam

Senior Associate Editor Glenn Zorpette on the loose in the streets of Madras.

to exploit technology and science to develop and join the world economy. But it is still unclear whether India's example will be instructive more for showing what, rather than what *not,* to do.

SOCIALIST TEMPLATE. Much of the mystery of Indian development—why so little progress seems to have been made in exports and living standards despite a large and competent labor force, abundant ambition and entrepreneurialism, and a number of impressive technical achievements—disappears in light of the country's history and priorities since it became independent.

Understandably wary of foreigners after centuries of subjugation, the first leaders of independent India embarked on a Fabian-socialist course whose destination was national self-sufficiency, and whose means to that end would be central planning and comprehensive five-year economic plans. Later on, in the 1980s, by which time most other nations had recognized trade as a tool of development and become more interdependent, India was more or less still clinging to the same old course and was therefore left out in the cold.

"We concentrated on satisfying domestic market demand," said Hermant S. Sonawala, chairman of Hinditron Services Pvt. Ltd. in Bombay, one of India's largest technical-electronics concerns. "India is not Hong Kong, Singapore, or Thailand, whose economies are based on exports. But because now we can basically satisfy domestic demands, people are demanding quality products, at international standards and prices."

Today, India has indeed become remarkably self-sufficient. But the price paid has been high. More than 40 years after the first controls were put into place to discourage imports and spur domestic production, the Indian economy remains constrained by a huge and baffling web of tariffs, quotas, and other restrictions. The economic isolation thus engendered has insulated many Indian industries and permitted them to languish with quality-control and manufacturing efficiency standards far below those necessary for success in world markets.

Indeed, despite all the talk of liberalization, conversations with high-tech entrepreneurs and businessmen reveal that many obstacles persist. "At the central [government] level, industrial-licensing and import-export restrictions are essentially gone," said Sonawala. "But at the state level—the working

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level—these changes have not yet been implemented. The bureaucracy still rules. Some of our laws are antiques."

The managing director of a prominent Indian maker of electronic instruments offered an example. "A man who knows nothing about electronics is asked to be in charge of clearing electronics components at customs. He probably doesn't even have a college degree. He was employed 20 years ago as a junior officer, and he's a senior official today, but with very little knowledge on any particular subject.

"I got two samples from Korea yesterday," he went on. "Multimeters. Each one cost $10. The customs duties cost me $100. Now, if I wanted to pursue a refund of the $100, I'd have to spend another $100 in clearing-agent fees—just because the customs officials don't understand.

"We have 60 or 70 engineers here. In their design work, they need small samples of ICs, maybe five or six, mostly simple ICs. By the time you wind up clearing all the goods, it takes weeks. And the customs charges and clearing and handling costs are in the hundreds of dollars. A $20 chip ends up costing you probably $120.

"Here, engineers are helpless. With the energy and efforts we put in, in any other country the outputs would be 10 times greater." High import costs apply to all kinds of technological tools and products; importing a run-of-the-mill personal-computer application program, for example, can incur fees that add up to about the cost of a brand-new PC, and are said to be an important cause of India's problem with software piracy [see "A bona fide industry, with a long way to go," p. 32].

BUREAUCRATIC LEVIATHAN. To most observers, the fundamental problem, and the most troubling legacy of central planning, is a vast and self-perpetuating bureaucracy, whose octopus-like tentacles touch virtually all aspects of life in India. "In fact, in the years to come, this is going to be our biggest handicap in competing globally in technology," said V. Prasad Kodali, an electronics expert and government official. The bureaucracy also seems to be permeated by corruption on all levels, from the minor but annoying bribes that often must be paid to get, say, water or electrical service, all the way up to allegations of huge bribes in defense purchases, and a recent stock scam in which well over a billion dollars may have been misappropriated (an exact figure has not been released).

The bureaucracy is ubiquitous and apparent even to casual visitors. For instance, a simple exchange of U.S. dollars for rupees at a Government bank in Bangalore last autumn occupied four bank employees, required the filling out of four forms (in duplicate), and took half an hour. The bank seemed to have at least three times as many employees as a comparable Western bank. Just entering India with a tape recorder, 35-mm camera, or camcorder is cause for a round of paperwork at customs.

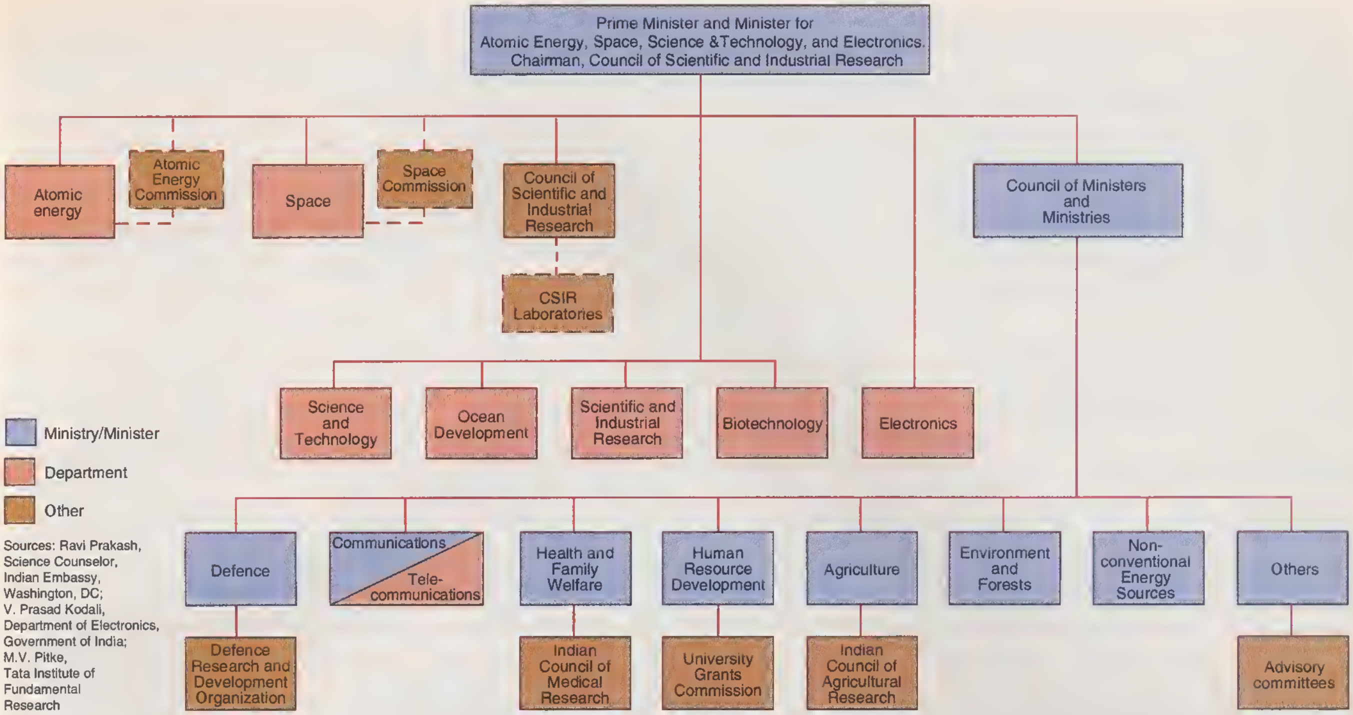
To understand how technology is developed in India, therefore, it is necessary to understand the central governmental bureaucracy, which is responsible for at least 80 percent of all technological and scientific R&D funding. Virtually every laboratory or technical project of any size in India falls under a Government department, ministry, commission, or committee (and sometimes more than one of the above). Some of these agencies—there are dozens of them—are nominally headed by the prime minister, who is also minister of space, minister of electronics, minister of chemicals and fertilizers, and so on.

In reality, however, each agency is headed by either a minister or a secretary to the Government of India, only a few of whom report to the prime minister (those of the departments of space and of atomic energy, for example). The rest report to a science and technology minister, who may or may not be the prime minister himself [see chart, next page]. The reasons why only a few report directly to the prime minister appear to have to do with the dates when the departments were founded and the reputation of their founders, as much as anything else.

Although their terms may be as short as two or three years, the secretaries of these departments wield almost absolute power and therefore have considerable influence over national R&D related to the purviews of their agencies. Yet many of these secretaries are career civil servants who bring to the job no experience or even knowledge of their agency's scientific or technical purview—or of any scientific or technical discipline whatsoever.

"There are some agencies headed by professional bureaucrats, who are brilliant people, but look at these technical challenges purely as administrative problems," said M. Anandakrishnan, the vice chancellor of Anna Uni-

Signs of ambition and entrepreneurialism abound in any Indian city, and especially in the southern technological center of Bangalore, where this picture was taken. Store-front self-improvement schools beckon with promises of careers in accounting, computer programming, and electrical engineering.



The sprawling Indian Civil Service was loosely modeled on the British Civil Service (which in turn borrowed from imperial China's mandarinate). In the science and technology apparatus, partially diagrammed here, the important groups are mostly departments and ministries. In general, departments report to ministries, and are headed by a secretary to the Government of India—the top administrative level of the Indian Civil Service. Ministers, on the other hand, are political appointees, designated by the president and prime minister. The prime minister, who is appointed by the president, is always head of several departments and ministries as well.

versity in Madras, one of India's more prestigious technical colleges. "They don't understand the precise technical aspects of the challenges [and] they only administer, not plan. They're firefighters, crisis managers. Unfortunately, the country is being administered more and more by bureaucrats and less and less by scientists and technologists. This is becoming a major concern for India's ability to compete in the global technology market."

There are the widely circulated stories, always told in private, of the department secretary who, on a visit to AT&T Bell Laboratories in the United States, boasted of a 5-μm fabrication facility being built in India, because he thought that his hosts would find a 5-μm facility more impressive than the 2-μm output the foundry was designed for.

C. K. Modi, recently head of the Department of Electronics and himself a career civil servant, denied that bureaucrats are any less fit to run technical agencies. "Whether departments are headed by a bureaucrat or a technocrat, I don't think that is a relevant issue. In my opinion, as far as officers are concerned, 75 percent of my officers are technical experts. So what is needed at the level of the secretary isn't so much [that he] be a technocrat himself, but rather [that he] be able to appreciate and evaluate proposals that come from industry, and from the technical officers in the department itself.

"The functions of the secretary of electronics are not purely technical," he added. "It's promotion of the industry, changes in tariff policies, advising the Government about exports," and similar responsibilities.

The acting head of the Electronics Department, N. Vittal, is himself an example of Modi's reasoning. Vittal, like Modi, has led several of India's technological departments without the benefit of any formal training in a technological discipline. Yet he is often cited as one of India's most indefatigable (and animated) champions of liberalization and reform.

BRIDGING THE GULF. All of these many central Government agencies with their legions of bureaucrats and technical experts have been powerless, however, to remove one of the biggest obstacles keeping India out of world markets. This is an unusually low level of industrially useful innovation—a by-product, it seems, of a chasm between Indian industry and the country's research and scientific establishments.

According to Peter Heydemann, the highly respected former science counselor at the U.S. embassy in New Delhi, this dichotomy between the two establishments in India is so extreme that it has led to "one of the smallest innovation rates in any [partially] industrialized country."

The gulf is hard to explain. E. C. Subbarao, cofounder and director of the Tata Research Development & Design Centre in Pune—one of India's most successful corporate laboratories—said: "Of the small amount of the world's R&D that goes on in this country, most of it is paid for by the Government. While [this Government-funded research] has its good features, there is not much accountability attached to it. The problems that are researched too often originate from the literature, rather than the needs of the country. There is very little linkage between R&D efforts and the end-user."

Whatever the reason, the fact is that industrially useful innovation is a rare thing in India. And, according to Heydemann, "one would be at a severe loss to identify sources from which this innovation could come." Most of India's 1300 corporate or industrial R&D laboratories preoccupy themselves for the most part with trouble-shooting and working with production managers to minimize kinks in production processes. "None of those that I saw could bring out a novel product," Heydemann said.

Within the Government is an advisory organization known as the Council of Scientific and Industrial Research, or CSIR. The CSIR also oversees some 40 key laboratories, which would have to be on the front line of any turnaround in Indian industrial innovation. "If an industry wanted to innovate, it would have to turn to the Government laboratories. The first set of laboratories it would have to turn to are the laboratories of the CSIR," Heydemann explained.

Most of the CSIR laboratories, however, are poorly connected to their corresponding industries and are therefore ill-equipped to assist them. The CSIR's director-general, S. K. Joshi, is "trying very hard to redirect the organization and its laboratories to support Indian industry, as it was once supposed to, but he is finding it very difficult," Heydemann said. Beyond the usual resistance to sweeping change, the CSIR, like almost all Government agencies, has been hit hard by

an austerity program begun a little over two years ago when the Indian government, under pressure from the World Bank, cut spending to reduce its budget deficit.

Notwithstanding all the barriers, there are a few dazzlingly bright spots in Indian industrial research, some within the CSIR and some outside of it. In the latter category is the aforementioned Tata Research Development & Design Centre (TRDDC), which does contract research for Tata Consultancy Services, the country's largest software consulting firm, as well as for an impressive international corporate clientele. The laboratory is an extreme rarity in India in that it is entirely self-supporting and derives a third of its revenues by doing contract work for non-Indian companies.

Among TRDDC's recent clients were Hewlett-Packard Co., for which the laboratory developed tools for migrating software for chemical instrumentation; Bell Northern Research, which needed a graphical query system to search an object-oriented database; and Indian Oil Corp., for which a production-scheduling system was created. "Some of the problems we work on may appear mundane," said director Subbarao. "But our solutions are as sophisticated as any in the world, and call for the very best in science and technology."

Another shining example of industrial R&D was incubated in the central government bureaucracy, of all places. The Centre for Development of Telematics (C-DOT), a nonprofit society created by the Government's departments of Electronics and Telecommunications, has designed and developed several telecommunications switches that have been installed all over India and are even being exported [see "Telecommunications," p. 43]. The center was the model for another agency, the Centre for Development of Advanced Computing, which has produced massively parallel computers, software, and application programs.

Receiving high marks within the CSIR system are the Central Leather Research Institute in Madras, which is formulating new tanning technologies to mitigate the damage done to the environment by existing techniques; the Indian Institute for Chemical Technology in Hyderabad, which has been active in synthesis of organic chemicals for biotechnology; and the Centre for Cellular and Molecular Biology, also in Hyderabad, which has been focusing on new processes and products.

The star of the system, though, appears to be the National Chemical Laboratory in Pune. Its director, R. A. Mashelkar, is one of India's leading industrial researchers and has made the laboratory an international source of expertise on catalysis, polymers, and industrial-chemical processes. Recent clients of the laboratory include Exxon, General Electric, and Oxychem in the United States; the Swiss chemical giant Ciba-Geigy; the Finnish fossil-fuels concern Neste; the Dutch multinational Akzo; and the Chinese government. According to Mashelkar, the laboratory earned about $250 000 from foreign contracts alone last year, up from almost nothing three years ago.

When not running the laboratory, Mashelkar can usually be found rattling the bureaucracy. "For too long we have been constrained by the rules, regulations, and restrictions which the Government has imposed," he said in an interview. Last year, he was chairman of a committee that produced a report recommending more autonomy for Government laboratories—for example, in spending earnings from consulting, recovering royalties from inventions springing from laboratory work, and forming and running affiliated companies.

"We want people to move from generating knowledge to a situation where they are exploiting it," Mashelkar said. "But why would they want to exploit it without rewards?" Last autumn, the report's basic recommendations were accepted by India's then minister-of-state for science and technology, P. R. Kumaramangalam.

Mashelkar is already leading a second committee to take on the much larger and more arduous task of streamlining the bureaucracy as it applies to research in general. "It's like this," he explained. "We've lost time because of the way we've done things in the past. We cannot reconstruct our past, but we can redesign our future. And that's what this committee is all about."

MANUFACTURING MORASS. A stifling bureaucracy and lack of commercially useful innovation are only two of the fundamental problems confronting Indian industry and negating its chances to compete for international markets. At least as serious are outmoded labor policies and a manufacturing sector so archaic and inefficient that India's share of global trade has fallen below 1 percent, down from 2.2 percent in 1950.

For all its socialistic inclinations, India does not have the public "safety nets" common in the West, such as financial assistance for the unemployed. Instead, the country's large, Government-owned companies, which typically either refine fossil fuels or manufacture automobiles, aircraft, steel, or heavy-electrical and telephone equipment, have themselves become safety nets. Any company with more than 100 employees cannot dismiss anyone without getting permission from the state or central government, which almost never grants it. The rules apply to both Indian firms and branch locations or subsidiaries of non-Indian companies.

A widely held view is that at least half of the workforce at the large, Government-owned companies could be dismissed without affecting productivity in the least. In conversations with top executives and Government officials all over India, nobody challenged this view. One Government official, who asked not to be named, said flatly: "Our public-sector companies are hugely overstaffed—by a factor of 50 percent, at least. There's so much featherbedding and Government pressure to add people. The head of any public-sector company has no freedom to make any big decisions. You have to get all these signatures, and you're not necessarily dealing with some high Government official. Very often you're dealing with some petty-minded flunkies."

While he was science counselor at the U.S. embassy, the well-connected Heydemann also looked into the issue. "I asked a friend of mine, who runs an industrial refrigerator factory, 'How many people work in your factory?' And he said, 'Maybe 15 percent.' He misunderstood my question. He says he goes to work sometimes and finds all of his workers sitting around doing nothing. Once he asked them, 'Why aren't you working?' They said, 'It's a nice day, and we felt like drinking tea.' He thought the only way he could make his people work for him was by being very nice, so they would want to work a little harder for him. It's terrible to think you'd have to work with such a workforce."

Thus India's industrial giants find themselves in a quandary: unable to compete with nimbler and efficient foreign multinationals, and also unable to pare down their own huge workforces and modernize their facilities to compete with offshore rivals. Wholesale dismissals and layoffs are not an option, most Indians insist, because of the massive social unrest and perhaps even starvation it would engender. Yet most also believe that fundamental change is necessary. "We have to have a market economy with a human face, rather than socialism without accountability, which is what we've had for years," said M. Vidyasagar, an enterprising young director of a defense ministry laboratory in Bangalore.

Some industrialists, it might be added, are convinced that India's large companies can become competitive without paring down to any great extent. "It's not a question of the number of employees," said R. N. Sharma, chairman of Hindustan Aeronautics Ltd., Bangalore, India's largest aerospace concern. "It's a question of the wage bill, and the productivity you get for those wages."

Indian factory workers are paid a minute fraction of what their counterparts in Western countries are paid, Sharma noted. So with the proper training, this theory goes, the large Indian labor pool could be harnessed to make up for the widespread lack of manufacturing automation. Such greater reliance on manual work could be especially successful in aviation and other industries demanding specialized, limited-scale manufacturing, in Sharma's view.

The theory is intriguing, but when it has been put into practice in India, the results have not been encouraging. Such manual manufacturing has been employed in the consumer electronics industry, for example, and the quality of the finished products has been uneven and seldom up to international standards. What's more, the level of manufacturing productivity has been quite low, when support costs are figured in.

"Looking at India as a place of cheap labor

Glenn Zorpette

Durable, dependable, and economical, ox carts are still used throughout India to haul all manner of goods and equipment, including satellite dishes. India's decades-old effort to use technology to improve its people's standard of living sets up innumerable contrasts between old and new, such as this scene in Channapatna, not far from Bangalore.

is a total misconception," said Kodali, the Department of Electronics official. "The labor may be cheap, but the productivity is low. India's strength is its technological manpower—its scientists and engineers. India is a good place for design and development."

PROFITABLE PARTNERSHIPS. The vast majority of sophisticated manufactured goods sold in India's domestic markets are ones developed primarily by non-Indian companies, typically Western multinationals. Usually, under some sort of joint venture, the product is manufactured in India with equipment and to specifications supplied by the non-Indian partner. (Even here, the Indian government placed limits on how much Indian companies could pay for non-Indian technology.) Under this scheme, the Western multinational got access to India's vast markets, while the Indian company learned all it could about the product, and, more importantly, how to manufacture it. This has been the pattern followed in products ranging from wristwatches to helicopters.

As they became more capable, however, the Indian companies have taken an increasingly active role in the partnerships, contributing more and more to the development of successive generations of products for their own markets. Lately, some of them have even struck out on their own with products that, although in most cases clearly influenced by those of their former Western partners, are arguably of Indian design and manufacture.

It is uncertain now whether Indian companies can sustain the trend, given the fact that the country's base of industrial research is embryonic and not held in high confidence by industry. "Industry says that the risk of investing in unproven, Indian-developed technology is much greater than licensing existing technology—even obsolete technology—from the multinationals," said P. V. S. Rao, a researcher at the Tata Institute of Fundamental Research (TIFR) in Bombay.

This lack of confidence, or "credibility gap," may be as much a bar to future progress at home as it is to acceptance of Indian products outside of India. "The credibility gap is so real that when we ourselves [at TIFR] were involved in a major development project [to promote Indian industry], one of my colleagues wanted to buy a personal computer," Rao explained. "The options were either a Sarabhai product, locally developed, or a Bush product, essentially an imported system being sold locally. And this member of the development team—who needed the computer to promote Indian industry—when it was a question of buying a tool for himself, he wanted an imported product. If a person in this environment, when it comes to a crunch, wants to play safe, you can see the difficulty of the problem."

This credibility gap has also helped suppress what little Indian industrial R&D has been done, according to a prominent Indian researcher. "A lot of money has been spent on R&D," he claimed. "But when it came to transferring that R&D into manufactured products, the Government officials would not support it wholeheartedly, because they did not have confidence in Indian technology."

"There were other reasons, too," for Indian officials to favor foreign technology and contractors, insisted one of the researcher's colleagues. They included "contacts with foreigh companies, future job opportunities for themselves or their children, official trips abroad for discussions or training, and even kickbacks."

The growth of competition for large contracts has reduced profit margins and therefore the bribes paid for big contracts in, say, telecommunications or defense projects. But "it's still a problem," the researcher said, and "everyone knows it."

Corruption is nothing new in the developing world and rears its head in developed countries with great regularity, too—witness Italy's recent scandals. But it seems to have become a part of the very fabric of society in India, from the legions of petty local government inspectors who must be paid off so that they do not find a problem necessitating shut-off of a utility service, all the way, apparently, to various top Government ministers, who were implicated in a recent multibillion-rupee stock scandal.

TALES OF THE LICENSE RAJ. Particularly notorious are the so-called "inspector raj" and "license raj." The former works like this: the government agencies that provide electricity or some other utility service send inspectors around periodically to check that wiring is sound, meters are working well, and so on. A little kickback apparently helps ensure that all is in order. According to Heydemann, "they'll find something that will lead to the electricity being turned off unless you pay 2000 rupees. It's a vicious system. They are officially inspectors, and are supposed to come for good reasons, but they're exploiting their position." The license raj works on a similar principle, the main difference being that licenses are still needed in India before

a business can expand, modernize, seek new business or enter new markets, and so on.

"Don't be a bribe groom," warns a Bombay billboard, showing a forlorn man behind prison bars. So widespread are the abuses, small and large, that Indian management magazines annually report on the bribes that businesses had to pay in the previous year, not unlike the revenue and other figures tallied up periodically by business magazines elsewhere in the world. A medium-sized company might pay more than $10 000 per year; a large company might pay a million dollars or more just in political contributions, which are often necessary to ensure good treatment.

Heydemann told of a conversation he had with the chairman of the Steel Authority of India Ltd. (SAIL) three or four years ago. The chairman disclosed that he was told by the Indian government what kind of steel to produce, how much to produce, to whom to sell, how much to sell, and what price he could charge.

Liberalization, Heydemann feels, offers the best possibility of changing all that. "The whole license raj could be abolished in a liberalized economy. No one should tell a steel company what to produce, whom to sell it to, and for how much. The chairman of SAIL should not have to bribe anyone to get a reasonable quota assignment.

"Such corruption distorts the marketplace dramatically," he added. "Decisions are made not on economic prospects. I still think the main problem is to get the Government off the back of industry."

BEST HOPE. If anything can bring this about, most observers believe, it will be the demands of joining the world economy. Either the restrictions and red tape will have to be brought under control or, it seems, Indian companies will simply continue to stagnate in isolation.

The central Government, moreover, may have more than enough to occupy itself, what with the challenges attendant on integrating India into the community of nations. Several technology-related issues, in particular, have surfaced, some repeatedly, and are contributing to India's continuing isolation and partial exclusion from the international community. They are India's practices in the area of intellectual property rights, which are mostly at odds with those of the West; the country's refusal to sign the Nuclear Nonproliferation Treaty or accept the Missile Technology Control Regime, an informal pact among Western nations that seeks to limit the spread of missile technology; and, least seriously, various labor and salary issues that have cropped up over the employment of Indian engineers outside India, at salaries well below the going rates.

Tolerance of violations of international patents and copyright is nothing new in India. In the struggle to improve living standards, patents on pharmaceuticals, chemicals, and other goods have been routinely ignored. More recently, the practice has bloomed into oftentimes flagrant violations of protections on various kinds of intellectual property, including software packages, microelectronics designs, and books and entertainment media, such as musical recordings and taped motion pictures. India, along with Brazil and Thailand, were designated "priority countries"—the most serious category—on the Office of the U.S. Trade Representative's last Special 301 Review of offenders against intellectual property rights. It was India's third consecutive appearance on the annual list.

India does not recognize product patents for any sort of chemical, including pharmaceuticals. For these products the country recognizes only process patents, meaning that any company capable of devising an alternative process to produce a pharmaceutical (or fertilizer, or petrochemical) is free to go into business producing it. In this context, relatively minor modifications of existing processes are usually interpreted as new processes.

In an agreement reached as part of the recent Uruguay round of the General Agreement on Tariffs and Trade, India will have to start recognizing product patents on drugs and other chemical products. However, as a developing country, India need not formally implement such recognition until the summer of 2005.

In industries not based on chemical processes, Indian patent law is adequate, most observers agree, but rarely enforced. There are signs, however, that as more innovation takes place in India, the protection of intellectual property will take root. "There's a strong demand now by Indian entrepreneurs for better protection," according to Heydemann. "If they innovate, they invest their own money to pay for that innovation. They need to capture enough of the profit to pay for it, and to capture profit, they need to keep the competition out of their markets."

This ground swell of support, however, appears to be a fragile thing, easily shattered by inopportune threats. In 1988, fed-up officials of the U.S. Trade Representative issued what amounted to an ultimatum to India, the gist of which was that if patent practices did not change, there would be serious repercussions—canceled scientific collaborations, and so on. The response was predictable. "No Indian entrepreneur could stand up for stronger patent enforcement, because he'd be immediately branded as being subservient to the Americans," Heydemann recalled. "It took almost until this year for Indian entrepreneurs to rally again around this flag of strengthening patent enforcement....I just hope the United States does not interfere now with ill-timed pressures."

NUCLEAR MIGHT. India's sprawling nuclear program, a source of national pride [see p. 36], has also been a source of high tension with the West since India's rejection of the Nuclear Nonproliferation Treaty (NPT) in 1973 and its test detonation of a nuclear device in the Rajasthan desert a year later.

That detonation, and the fact that India has all the equipment and technology necessary to produce bomb-grade plutonium, has led many analysts to conclude that India has a clandestine program that could rapidly assemble nuclear weapons. The plutonium for the weapons program was recovered from spent fuel that was reprocessed after being irradiated in a couple of research reactors at the Bhabha Atomic Research Center (BARC), in Trombay, not far from Bombay.

India has one fuel-reprocessing facility at BARC and another, problem-plagued one at Tarapur; the plutonium was recovered at these two facilities. A better reprocessing plant is nearing completion at Kalpakkam, near Madras, to the east near India's southern tip. Based on studies of these facilities, it is believed that India could have produced some 400 kg of bomb-grade plutonium by the end of next year—enough for some 50 bombs.

India's persistent refusal to sign the nonproliferation treaty has led to a number of conflicts and tense situations with the West. A longstanding one concerns two 160-MW reactors at Tarapur, about 2 hours north of Bombay, that were built with financing from the U.S. Government's Agency for International Development. The General Electric boiling-water reactors are operated under a complex agreement that called for the United States to provide the enriched uranium fuel until October of last year, and for India to store all spent fuel indefinitely and not reprocess it without U.S. permission.

However, because of India's refusal to sign the treaty, the United States stopped supplying enriched uranium to India in 1983 and arranged for France to do so until the agreement ran out. Now that it has, France, and all other nuclear nations, have declined to supply more fuel unless India becomes a party to the treaty. India shows no sign of taking that step, though it has so far not reprocessed the fuel.

The situation could change, however. India seems barely to have managed to supply enough domestically produced fuel for its small group of indigenously designed reactors, the heavy-water types that use natural uranium fuel. Electricity is in extremely short supply all over the country [see "Electric power," p. 51], so the continued operation of Tarapur undoubtedly matters. A very small gas-centrifuge–type uranium enrichment plant at Trombay is believed inadequate to supply the reactors. Another enrichment plant, near Mysore (in southern India not far from Bangalore), has been plagued by operational problems, according to a U.S. government official. So the estimated tonne or so of plutonium in the spent fuel from Tarapur, a limited amount of which could be recovered by Indian reprocessing plants and turned into fuel, must look tempting to Indian officials.

Whatever the outcome of the Tarapur situation, India's continued rejection of the nonproliferation treaty seems certain. "We feel it is a discriminatory treaty," said R. Chidambaram, chairman of India's Atomic

Energy Commission and the head of the country's entire nuclear effort. "You can't divide the world into two parts—weapons states, and non-weapons states."

"On the other hand, our record in the export of sensitive technology is blemishless," he said in an interview. "We have never exported sensitive technology and we will certainly never do it in the future." Such technology apparently excludes research reactors, which Chidambaram said India is willing to export, under the safeguards of the International Atomic Energy Agency in Vienna. He declined to comment on the alleged military nuclear program, or even to confirm its existence.

The controversy related to the Missile Technology Control Regime dates to January 1991, when the former Soviet Union agreed to sell the Indian Space Research Organization $350 million worth of sophisticated cryogenic (liquid hydrogen and oxygen) rocket boosters and the technology to manufacture them. The United States initiated sanctions against the two countries, citing the deal's violation of the control regime. Last July, the Russian government bowed to U.S. pressure and canceled the deal. India responded as it has in the past when denied sensitive technology—by vowing to develop the technology on its own. Experts believe this will take about seven years.

The dispute over labor, finally, is a relatively new one. At issue is the temporary employment, in places like California, of Indian technical professionals—mostly software specialists and engineers—at rates far lower than what a local with comparable qualifications would be paid. At a time of severe economic recession in California, the contract employment of many technical specialists from India, the Soviet Union, and other countries—at salaries far below those prevailing in California—has struck some as an unfair subversion of the U.S. technical workforce.

Last autumn, a group calling itself Californians for Population Stabilization filed suit in California state superior court against Tata Consultancy Services (TCS), India's largest software consulting firm, and Hewlett-Packard Co., Palo Alto, Calif., accusing the firms of conspiring to circumvent U.S. labor laws related to minimum pay, benefits, and taxation. The suit further alleges that TCS treats its overseas employees as indentured servants, prohibiting them from seeking other opportunites while they are abroad.

Yash P. Sahni, president of TCS, denied the charges. "At any given time, we have about 350 people in the United States," who stay about a year each, he said. Before they go, each must sign an "overseas agreement," requiring them to return to TCS in India for at least two years after their foreign posting. If they do not return, they are liable for $30 000, fair compensation for TCS's investment in them and the damage done to the company's reputation by such departures, in Sahni's view.

TCS employees are sent abroad because most projects require that part of the work be done at the customer's offices, Sahni insisted. Regarding the salaries, he said that "we do not pay wages there, we pay expenses"—for an apartment, automobile, and other necessities. "They continue to receive their [regular] salaries here" in India. A highly skilled and experienced engineer in Bangalore or Delhi might earn the equivalent of $400 or $500 a month.

Restrictions on the employees' professional mobility are necessary, Sahni added, to protect TCS and its image. Every year, he said, TCS used to lose a few employees, some to so-called job-shopping agencies, who hold out the prospect of a relatively high-paying job in the United States. Lately, however, the defections have been stanched by legal proceedings against some of the defectors.

"We took it up as a matter of principle," Sahni said. "We spend a lot training these people. How does it look—we've paid for an apartment, a car for him, and insurance. One guy was sick, so we paid $25 000 for his medical care. And after a month or so, he disappeared. We have this commitment to the people who are giving us visas that our employees are going for certain projects, and that they will come back when the projects are done."

LONG, LONG ROAD. Although formidable now, these problems may prove mere pebbles in the path of the juggernaut that India's economic liberalization has become. Although the road might be long and progress often slow, the direction is clear. All the major political parties, with the exception of those on the extreme left, support liberalization in one form or another.

"We've only scratched the surface," said Sonawala, the chairman of Hinditron, the diversified electronics giant. "In the 1950s, the guided economy was necessary, or else we would have never come out of our rural, agricultural economy. But the time has come for the Government to become regulatory

Glenn Zorpette

More than a third of the Indian population is under 14 years of age, and they are the most likely beneficiaries of the long process of liberalization, as well as other efforts to bring India's health indicators, public infrastructures, and utilities up to the level of other Asian countries.

rather than supervisory."

Even those who staunchly support liberalization, however, do so not without reservation. "If liberalization had happened eight or 10 years ago, would we even have a C-DOT?," asked P. V. S. Rao, the researcher at TIFR, referring to the Centre for Development of Telematics, whose telecommunications switches have met with such success. "In a totally liberal situation, when we are getting technological products from abroad, could an organization like a C-DOT emerge? No, there wouldn't be a chance. If that is the case, do countries like India keep exporting grains and textiles, and importing computers, automobiles, and medicines?"

Possibly, but not likely. With India's technical legions, and pervasive entrepreneurialism, liberalization, given time, could supply a large part of what has been missing. And the rate of liberalization's progress will be set mostly by the perpetual, day-to-day struggles between the reformers, who are mostly younger, well-educated officials now starting to get into positions of authority, and the bureaucrats in the Indian central and state governments. The latter, still a potent force, correctly see liberalization as an encroachment on their domain and cling tenaciously to power, even if it is negative.

A development worth noting in this regard is the professional survival of Manmohan Singh, the Indian finance minister and most influential champion of reform. In the wake of revelations that somewhere under $1.5 billion in public funds had been embezzled in a stock and banking scandal, Singh's nonchalance struck many as appalling. The embezzled money has never been recovered or even precisely tallied for the public.

Nonetheless, Singh is still finance minister and the current best hope for progress in liberalization; in fact, if anything, his survival of a noisy campaign for his ouster has elevated him in the public eye. But like all other movers and shakers, he remains vulnerable to what is known in India as the "crab symptom," after an old fable.

It seems a fishing boat was out crabbing, and a sailor noticed that one of the buckets had no lid. Certainly the crabs would jump out, he said. But the captain just laughed and insisted they would not, because they were Indian crabs. The point, which is said to be immediately understood in India, is that as soon as one crab rose above the others, they would pull it down again.

More than a few have been struck by the irony of India's current situation. The fundamental problem now is Government bureaucracy and intervention, but virtually all are looking to the Government to solve it.

"Everyone is looking to the Government, which takes the responsibility of telling everyone what to do," Heydemann marveled. Asked to explain it, he just shook his head and smiled. "The more I know about India," he said, "the more difficult I find it to predict or analyze things that are typically Indian."

Software: a recognizable export, at last

In less than a decade, Indian software exports have soared more than tenfold, from US $24 million in 1985 to an anticipated $350 million this year. They have provided the country with its first international recognition for a high-tech export, as well as some much-needed foreign capital. In the two articles that follow, the top executives of two of the largest Indian software houses describe the strengths, character, and history of India's software industry, and acknowledge the challenges that must be met if it is to become the $1-billion-a-year industry many believe it will soon be.

A bona fide industry, with a long way to go

Faqir C. Kohli   Tata Consultancy Services

Among India's many high-technology endeavors, commercial software consulting is arguably the only one that has attained a measure of recognition worldwide. Last October, a 250-person-year software project went into use at Schweizerische Effekten-Giro AG, the Swiss securities clearing corporation. Not long before, a reengineering and migration project for Britain's Sun Life Assurance Society in Bristol, requiring over 150 person-years, was completed. For the United States, 100-plus person-years went into development projects for Fireman's Fund Insurance and AT&T Paradyne. These are just a few examples of projects from a couple of the largest Indian software houses.

These days, a computerized network links 430 districts on the subcontinent, so that big projects may be organized through exchange of electronic mail and data. Hardware companies are getting into the software business, and the use of advanced software-writing tools and quality principles is on the rise. Clearly, software consulting has shaken off its cottage-industry origins and is coming into its own.

Though its growth has been exponential, India's software business and the computer industry of which it is a component still have a long way to go. Production by the country's entire computer industry in the most recent fiscal year (1992–93) was on the order of US $1 billion, nearly two-thirds of which derived from hardware and the rest from software. This $1 billion figure is not even a half of a percent of India's gross national product, proof that the domestic market is in its infancy. Even the much-vaunted exports, which may reach $350 million this year, are a marginal presence on the world scene.

Such peculiarities of the Indian software industry—its belated rise and strong emphasis on export—are the product of a unique and very short history. Before 1986, India's few and isolated efforts in software could hardly be called an industry. Software, along with other forms of high technology, was perceived as being utterly disruptive of employment. There was little or no awareness of the usefulness of information technology in building up and operating a society's infrastructures. In many areas where the technology's use was already well established in developed countries—manufacturing productivity, services and administration, managing and monitoring national plans, and disaster and crisis management—it was applied in India either ineffectively or not at all. Yet another hurdle was the limited hardware base, a result of meagre manufacturing resources and severe restrictions on imports and foreign exchange.

Since 1986, however, there has been a growing recognition that greater use of computers is necessary to step up the tempo of economic and social development. The stifling maze of restrictions is gradually being dismantled, industries are being encouraged to develop a computer culture, and the export of software services is being actively nurtured. In short, computerization has become a part of government policy.

Such activities have helped create a software industry worth about $380 million in the last fiscal year, about $225 million of which was derived from exports [see chart, p. 34]. Just a few years ago, the industry generated around $150 million, split almost evenly between the domestic and export markets.

Perhaps most heartening, the domestic software industry is beginning to mature. While one-of-a-kind, customized software still accounts for about half the market in India, the share of mass-market packages and application programs is on the increase. Indian personal-computer packages for bilingual word processing, desktop publishing, and finance and accounting are available. There are computer-aided and other software engineering packages and tools, drafting and computer-aided design products, and anti-virus programs.

What they all have in common is something called "Indianness," that is to say, they are directed toward the Indian user, taking into account the country's unique

business requirements and industry norms.

The trend among Indian software companies is specialization in, for example, communications software, software engineering tools, or application software for sectors like banking, or health care. Currently, there are more than 150 software companies that employ at least 20 people, and most of these 150 are involved in the export market. Together, they employ more than 32 000 professionals, and the largest—Bombay-based Tata Consultancy Services—has a staff of more than 3500.

All told, almost 60 percent of India's software exports go to clients in the United States [see pie chart, p. 36], while Europe and Japan account for about 25 percent between them. Indian companies now work on almost all platforms, and have experience with most computer-aided software engineering tools, relational database management systems, graphical user-interfaces, and object-oriented technologies.

More and more of these exporters are developing software in India, rather than providing technical workers who work at the customer's site. Nowadays, the total amount of work done offshore and that done on-site are about the same.

In addition, a number of non-Indian multinational companies have set up dedicated software organizations in India, which are either wholly owned or joint ventures with Indian firms. These organizations supply services and skilled professionals to the multinationals' operations elsewhere in the world. Examples include Unisys, which has a joint venture with Tata called Tata-Unisys; IBM, which also has a joint venture, called Tata Information Systems Ltd.; Texas Instruments, whose Bangalore-based software operation dates to 1987 and was the first in India; and Siemens, Hewlett-Packard, British Telecom, Citicorp, AT&T, and Hughes Network Systems.

A variation on this theme is the migration of a company's data-processing operations to India. Swissair, for example, has a joint venture with Tata Sons Ltd. in Bombay, to handle the revenue accounting of its inter-airline billing and reconciliation.

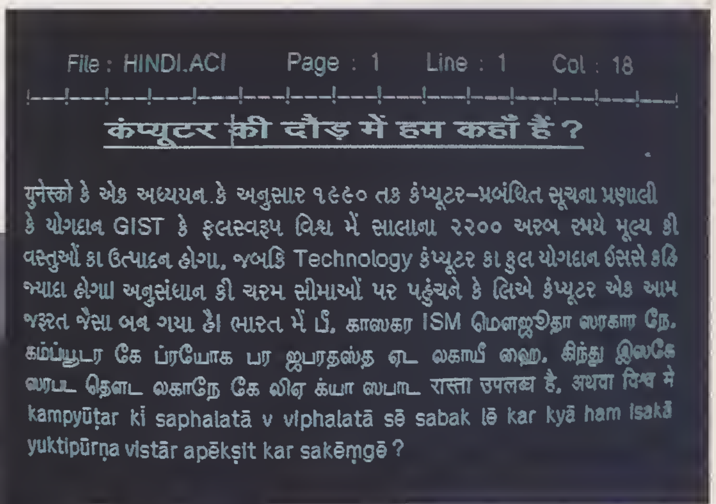
Yet another variation is offshore maintenance. With a time-zone difference of about 10 hours between New York City and Bombay, a fault logged by a client at the end of the business day in Manhattan can often be addressed by the next morning there, without anyone losing sleep. Such remote partnerships are being facilitated by the installation of dedicated 64-kb/s links between key centers in India and various international locations. Multiple data links are becoming available for videoconferencing, data transmission, and voice communication.

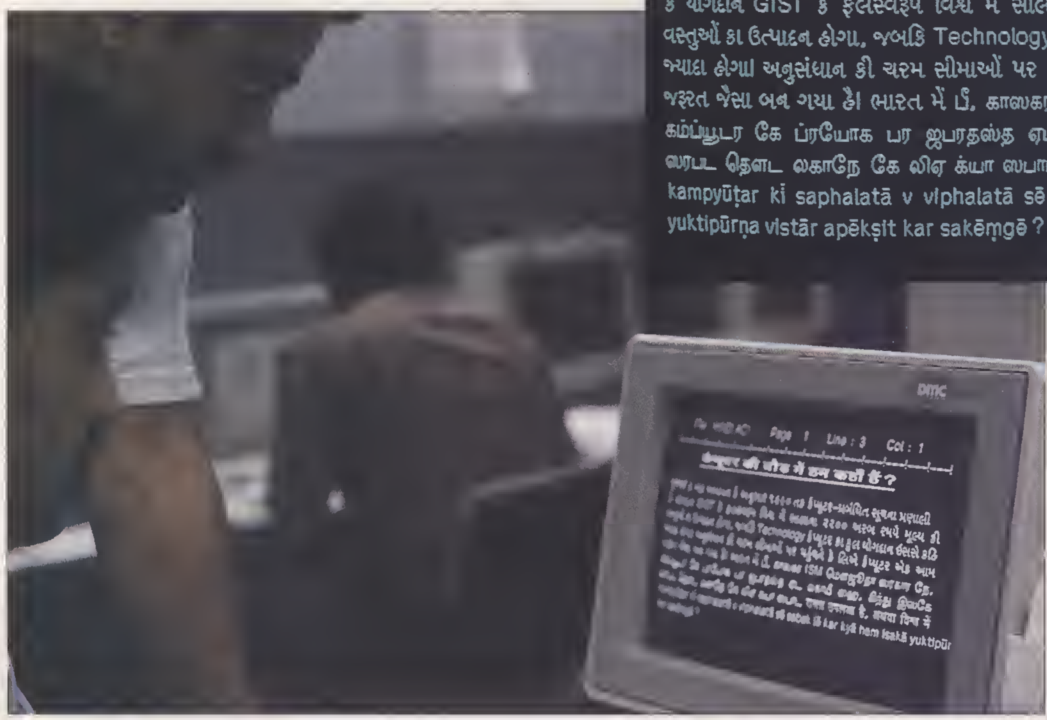
SOUND FOUNDATION. The software industry employs people with an assortment of technical backgrounds, not just in computer science or information technology. India's large software houses invest heavily in skills training and continuing-education programs, to keep abreast both of developing technology specific to an industry and of conceptual advances in software, as well as to make up for an uneven exposure to software engineering and technology. Some Indian companies spend as much as 5 percent of their annual revenues on training.

Perhaps the biggest effect of these efforts will be on quality—all-important in this time of intense global competition. In order to enhance their acceptability rates and quality image, many software firms are working toward certification under ISO 9001. This certification covers design, development, reengineering, and maintenance of software and corresponds to level three, indicating robust maturity, on a framework established by Carnegie Mellon University's Software Engineering Institute in Pittsburgh. Already, many are looking beyond this standard to the Malcolm Baldrige National Quality requirements, which call for total quality management and benchmarking against accepted quality management systems under various categories.

What would also help the Indian software industry's image abroad would be a tougher line against piracy. Software piracy in India stems from the high cost of imported software, whose prices are so bloated by customs duties that a single package may cost almost as much as a brand new personal computer. To counter piracy, many software companies have started manufacturing their products in India, making them cost-effective.

In fact, all of the necessary laws to protect intellectual property are contained in India's Copyright Act of 1984. However, they need to be implemented and enforced.





Glenn Zorpette (photos)

With its many languages and scripts, India needs to be able to represent the same word in different alphabets. Software to perform transliteration (as the function is known) among 14 Indian scripts has been developed at the Centre for Development of Advanced Computing (CDAC), in Pune. This kind of software finds uses in enabling English-language word processors to be used in a variety of Indian languages.

Recently, the government's Department of Electronics set up a national committee to deal with the issue. The industry has followed suit with an Indian Federation Against Software Theft, with the object of rooting out and prosecuting pirates.

THE FUTURE. Software will be a growth industry in India for quite some time. The rate of this growth, however, will depend on deeper penetration of computers and computer technology into business, industry, and many other aspects of Indian society.

Software export is very dependent on the size of the domestic market. Without a sizable domestic industry, a country cannot create the necessary capabilities and build momentum in innovation, design methodologies and techniques, quality, reliability, and credibility—the basic requirements for success in exporting software and services. In view of this, India has no choice but to build a viable, sound, mature, and large domestic computer industry.

Edward Yourdon, the U.S. software guru, visited India in 1989 to research a special issue on the country for his monthly publication, *American Programmer*. He wrote that "to build a viable export industry, India must have a strong domestic computer industry as a foundation—computers must be part of every business, part of the culture, part of the social infrastructure. At a level of one quarter of one percent of the overall GNP in 1990, India's computer industry is barely visible."

Clearly, a revolution in quality and volume of the industry can be fomented only by greater sense of the value of software within the domestic market. Not only would such a mind-set help combat the piracy problem, but from a strategic standpoint it is important for growth. For only through this kind of thinking can the Indian software industry get better at managing software development, engineering high-quality products, and understanding end-users' concerns of usability, maintainability, and service.

That said, the strengths of the Indian software industry are formidable, and include:

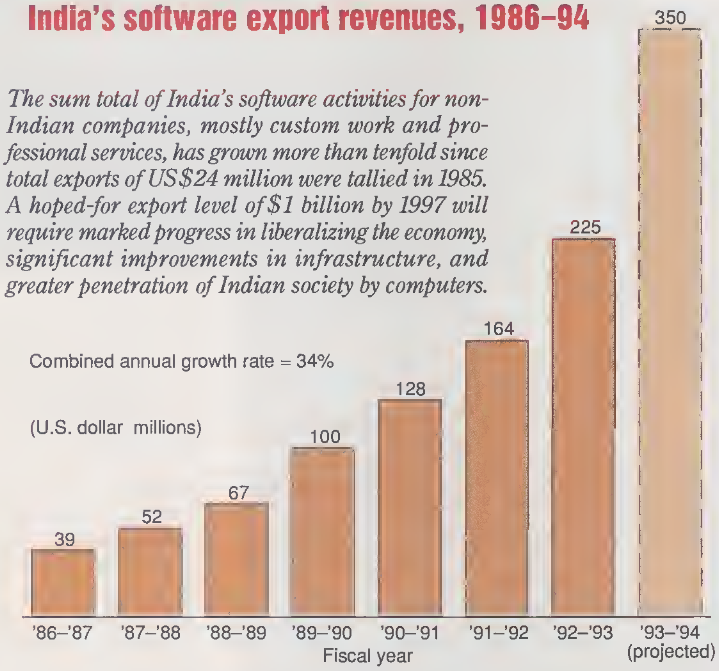
- An abundance of intelligent, motivated, and educated young people who have what it takes to be systems analysts, business consultants, and problem solvers.
- Potentially large, deep markets for computer and information technology.
- A demonstrated ability to deal with hardware and software technology in designing and delivering large and complex software systems.
- Ample entrepreneurial spirit.
- A government whose attempts at reform and sympathetic policies have paved the way for international competition and possible catalysis of the industry.
- A strong tradition in research and education in mathematics.
- A growing awareness of, and experience in, the technology development cycle and its management.

All that is missing is a robust and sophisticated computer market and culture at home. When that last piece is finally in place, India's software industry will become the truly viable, vibrant, and competitive business that it is fully capable of being.

Faqir C. Kohli (F) is director-in-charge of Tata Consultancy Services, the largest software firm in India and one of India's well-known Tata Group of companies. A former director of the IEEE's Region 10, he began his career in power engineering with the Tata Electric Group in 1951. He has received many awards for his work both in electric power and in information technology.

India's software export revenues, 1986–94

The sum total of India's software activities for non-Indian companies, mostly custom work and professional services, has grown more than tenfold since total exports of US$24 million were tallied in 1985. A hoped-for export level of $1 billion by 1997 will require marked progress in liberalizing the economy, significant improvements in infrastructure, and greater penetration of Indian society by computers.



Source: National Association of Software and Service Companies, India (Nasscom)

A partner on the other side of the globe

Ashok Soota Wipro International

In Silicon Valley, at a software vendor specializing in Unix applications, Derek Smith was having problems making the Solaris operating system from SunSoft, a subsidiary of Sun Microsystems Inc., run on his Intel box. So he dialed the number for the toll-free helpline. A moment later, a phone rang at Orbit 1, a technical support center in the valley managed by Wipro Infotech, headquartered halfway around the globe in India.

Orbit 1 is an excellent example of high-technology leveraging. While it provides support for original-equipment manufacturers and independent software vendors who use SunSoft products, SunSoft itself works on higher versions of its Solaris operating system. In effect, Orbit 1 interfaces the technology providers, like SunSoft, with those who package technology, like Derek Smith.

The support center consists of a band of quick-to-react engineers who have a unique set of engineering skills. They were hired from one of the leading Indian engineering colleges, and in their time with Wipro—on average three years—had ported Unix to several platforms, writing device drivers and special end-user enhancements as needed. Moreover, to sensitize them to the needs of an international set of customers, the Bangalore company had the University of California, Santa Cruz, train them in multicultural communications.

It was one of these engineers, who had access to Solaris source code, who simulated Derek Smith's problem on-line. In just a few hours, Smith got a call back advising him how to solve his problem.

This example of technological capability is only one of many that have helped propel the Indian software industry to a 12 percent share and a leadership position in the world's market for what is called outsourced software (software work done outside a company by hired consultants or experts). It was not always so. For years, India had just one major player, the pioneering Tata Consultancy Services. Started in 1969, this company must be credited with being the genesis of India's modern software industry.

For many years, the dominant software development activity was the conversion of application software for one mainframe to use on another. Later, manufacturing, financial, and other programs, as well as some vertical applications, began to be developed. The *modus operandi* was usually to send programmers to the overseas country, earning India the moniker of a body shop.

Curiously, India's earlier policy of a protected, self-sufficient industry, which damaged the country's competitiveness in other fields, contributed positively to its

Leading software exporters in 1992–93

India's top five exporters of software expertise account for almost half of all revenues earned. Nonetheless, the country's pervasive entrepreneurialism is evident from the fact that more than 450 Indian companies export software-related services—and the smallest 200 of these share a combined revenue of only $330 000.

current software capabilities. In the early 1980s, many Indian computer companies entered the closed environment, setting up centers that undertook to design virtually everything, including chips, operating systems, compilers, graphics, and software development tools. In telecommunications, too, the country grappled with the development of rural exchanges, switching systems, and other equipment. And having no base of proprietary mainframes, India adopted open systems and distributed computing even before they became popular in the West. All this activity bred a core of specialists larger and more capable than could be kept busy by India's small domestic computer market.

Then, in the late '80s, the winds of liberalization brought in competition, and many of these integrated companies folded or found it not feasible to serve the Indian market alone. The pool of talent then released gave rise to new entrants who forged a software industry with a strong export orientation.

OPENING MARKET. Many of the Indian computer companies entered into joint ventures with multinationals, mostly U.S.-based ones, which were delighted with the technological skills, particularly in Unix. Most of these joint ventures, like Digital Equipment India and HCL-HP, began to do R&D for their overseas partners.

But the first of the multinationals was Texas Instruments Inc., which in 1987 set up a subsidiary in the south, in Bangalore, for developing computer-aided design tools and chip design. Texas Instruments' venture went through teething troubles, mainly connected with satellite communication links, and big players watched its efforts with skepticism. Fortunately, Indian government officials had begun to realize that, after missing a number of major opportunities, they should try not to miss this one, for which India seemed to possess natural competitive advantages and which could be critical to the country's future. Even more fortunate, the Department of Electronics and Videsh Sanchar Nigam Ltd., the country's external telecommunications carrier, had leaders committed to resolving the communications issue.

The measure of their resolve is evident from the fact that India today has seventy 64-kb/s links, apart from other channels, providing extensive data communication highways to the world. The Department of Electronics also cut through bureaucratic red tape to introduce many innovations, like Software Technology Parks with the kind of ready-built infrastructure and resources needed to assist entrepreneurs and thereby encourage new investments.

Quickly responding to the changed environment, Wipro and a few other players effected a paradigm shift. Wipro repositioned its R&D operation as a laboratory for hire, and its customer list today includes many Fortune 100 companies in computer design, telecommunications, data communications, chip design, and other areas.

Observing all this, many other foreign companies began to look seriously at India. One of them was Verifone Inc., Redwood City, Calif., whose business it is to automate and speed up credit card and other retail transactions. It needed extensive video, voice, and data links between its R&D and manufacturing operations. The R&D facility that Verifone set up in Bangalore exceeded its expectations; by now it is the largest of the six R&D labs they have scattered around the world, and is still expanding.

So what does the Indian software scene look like today? A few figures are helpful, as is a look at the players and the work they are doing.

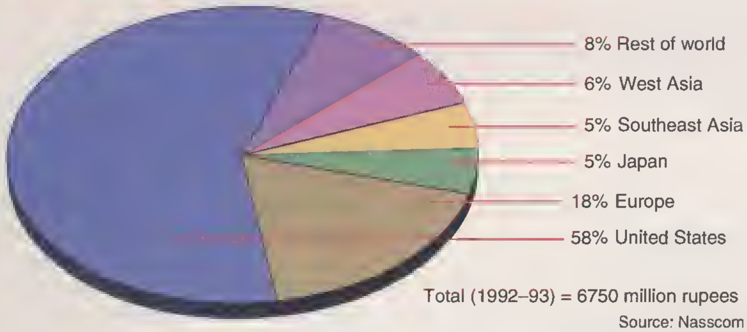
TODAY'S SCENE. There are about 250 software companies in the country plus 350 start-ups. The software industry employs 100 000 people and can develop several thousand professionals every year. The size of the industry is just US $500 million, to which exports contribute about 50 percent. Though small, it is growing rapidly at a compounded average growth rate of 54 percent for software exports over the last 10 years. About 80 percent of the software development activity is located in three big cities—Bombay, Bangalore, and Delhi—but many new locations are developing at cities such as Hyderabad, Pune, Trivandrum, and Madras. A high proportion of the software exports (59 percent) is still prepared on-site, according to the National Association of Software and Service Companies in New Delhi.

Fortunately, the offshore component is flourishing in step with the growth of experience and the development of data communication links. The United States, which accounts for 58 percent of India's software export earnings, is the largest market, while five more members of the Organization for Economic Cooperation and Development account for 22 percent of total exports.

As for the players, the queen of India's software companies is still Tata Consultancy Services, which is headquartered in Bombay and has some 3500 employees at locations around India and the world. This year the company is expected to pass $100 million in turnover. The company recently completed a project for Sunlife Assurance (in Britain), worth an estimated $14 million, making it one of the largest reengineering projects in the world. Tata Consultancy also invests heavily in R&D to improve such aspects of its business as software development productivity and project management models.

The next largest Indian player (not counting subsidiaries of foreign firms or joint ventures between Indian and non-Indian companies) is Wipro, which, apart from the system software skills mentioned earlier, has experience with a number of platforms and has developed applications in

Worldwide Indian software exports in 1992–93



The United States, Japan, and Western Europe account for about four-fifths of India's software exports. Lately, labor issues have clouded the India-U.S. software relationship, and it is likely that future growth will be most rapid in Europe and Asia.

a variety of areas, like banking, work-flow automation, and multimedia. Wipro was also the first company in India to develop an internationally successful application-software package, which was called Instaplan.

The third-largest purely Indian software firm is Infosys in Bangalore, one of the fastest-growing software houses. Recently, it helped Reebok, the British-based footwear manufacturer, to dramatically improve efficiencies through a manufacturing package and composite manufacturing-information system.

There are many more companies: some well-established like Computer Maintenance Corp., Patni Computers, the National Institute of Information Technology, and Datamatics; others young and entrepreneurial like Encore; and yet others quite specialized, such as SIS, which focuses on niche applications like ISO 9000 certification. Along with these are a number of joint ventures between Indian and non-Indian companies.

Most of these companies do some of their work for the non-Indian partner, but also bid for projects from other customers from around the world. Many of them are working on projects in such cutting-edge applications as speech recognition, multimedia, and mobile computing.

Finally, there is the growing list of organizations that, encouraged by the success of TI and Verifone, have set up their own fully owned subsidiaries. These include the likes of Motorola, Hughes Communications, Grindlays Bank, Deutsche Bank, and Citibank. These organizations are using the Indian centers to develop products in areas of the greatest significance to them in worldwide markets.

India's software industry is growing because it offers quality, a strong technology base, and hefty cost savings, particularly when the work is done offshore. Many of the leading players have invested heavily in software tools, computer systems, data communications, videoconferencing facilities, ISO 9000 certification, training, and infrastructure.

Even with so many tools and resources, the average cost of developing software in India is only about $1800–$2500 per person per month, a third or quarter of costs in the United States, western Europe, or Japan. With its attractive prices, one important segment to which Indian software caters is the start-up organization funded by venture capital, which typically needs to stretch its budget and bring new products to market quite rapidly.

HAZARDS AND HOPE. All the above does not mean that everything is smooth sailing and problem-free. First, India has a track record of missing opportunities, and there is growing competition from software writers in Russia and other countries of the former USSR, China, and elsewhere. Recessionary conditions in the West are leading to such protective measures as visa constraints and curbs on outsourcing.

Moreover, India will need to make heavy investments to gain a larger share of world markets and maintain expertise in the latest technologies. R&D in the automation of software is inadequate, and Indian marketing has been poor. The fact is, much of the large business has come from customers like General Electric and Bell Northern Research, who had well-defined outsourcing plans, rather than through good marketing. Finally, though multinationals may use the Indian base for developing state-of-the-art products, hardly any mass-market application software that can be truly called Indian finds shelf space in world markets.

On the other hand, there are many new opportunities. For example, software skills can be used for design-intensive hardware projects. An integrated company like Wipro can also bid for manufacturing, as was successfully done in a recent design for a multiprotocol communication server. In that case, the U.S. customer had originally intended to get the manufacture done in Taiwan.

With increasing awareness worldwide of the benefits of leveraging, India is set to play a valuable part in distributed software development. In fact, it continues to confirm the paradox of having its tail in the 19th century and its head in the 21st, as its software industry positions the country as a high-tech provider of services, technology, and products in the world market.

Ashok Soota is president of Wipro Infotech and vice chairman of Wipro Systems Ltd. The Bangalore-based firms have interests in computer software and hardware design, and manufacturing. He is also president of the Manufacturers' Association for Information Technology, India's largest computer industry association.

Nuclear technology: power to the people

With its enormous population and lofty development imperatives, India's need for electric energy is prodigious. At least 300 000 MW of capacity must be added by the middle of the next century if the country's average per-capita consumption is to approach levels high enough to ensure a reasonable quality of life for its people. But its fossil fuel resources are modest, and the nation has no choice but to exploit nuclear power if it is ever to achieve this goal.

The peaceful application of atomic energy has a special place in independent India's technology development efforts, having been one of the first strategic technologies pursued on a grand scale for the sake of national self-sufficiency. The program was begun 40 years ago by Homi Bhabha, the great Indian physicist. It has since grown large and comprehensive, employing more than 15 000 scientists and engineers in four Government research centers alone; there are in addition several industrial units. The program covers the generation of electricity; the use of radioisotopes in industry, agriculture, and medicine; and the transfer of developed technologies to nonnuclear industries and activities.

R. Chidambaram, Anil Kakodkar, and Placid Rodriguez   Department of Atomic Energy

To electrify more of the country and meet its needs for the foreseeable future, India has devised a three-stage plan. In the first and current stage, a series of pressurized, heavy-water reactors (PHWRs) are being deployed. They will be used to generate not just electricity but also plutonium for the second stage, when a group of liquid-metal, fast-breeder reactors will be commissioned. In

the third and final stage, the emphasis will shift to thermal breeder reactors and reprocessing technology operating in a uranium-233–thorium-232 fuel cycle. Only by exploiting such a cycle can India—which has the world's largest known re-serves of thorium—hope to achieve long-term energy security and self-sufficiency.

One of the most important milestones in the program's first phase was reached in 1983, when the first indigenously designed and constructed PHWR was commissioned at the Madras Atomic Power Station at Kalpakkam in Tamil Nadu, India's southernmost state. Since then, four more of the reactors have come on line, five are under construction, and four are in the planning phase. All of the operating reactors are 220-megawatt-electric (MWe) units. The design for a 500-MWe model has also been completed, and the first reactor of this design is ex-pected to begin construction later this year.

India's PHWR design was based on the Canadian Deuterium (Candu) reactor, two units of which were built, partly with Canadian collaboration, not far from Kota, in the northwest state of Rajasthan. The PHWR design was selected because its natural uranium oxide fuel is relatively easily produced. Apart from the reactor itself, all the infrastructure—the heavy-water production equipment, zirconium-alloy products, fuel, and instrumentation and control systems—are of Indian design and construction.

The country's proven uranium reserves are modest, however, amounting to only about 67 000 metric tons. In view of the size of these reserves, the plan is to limit PHWR construction to a capacity of about 10 000 MW in all. Available reserves should be adequate for sustaining operation of this kind of PHWR capacity for 40 years, by which time the second phase (the fast-breeder program) will be well under way.

The foundation for this second phase was laid not long ago with the construction of the fast breeder test reactor, which first achieved criticality in 1985. The system, whose design was inspired by the French Rhapsodie reactor, has a thermal rating of 40 MW. So far it has been operated up to only 10 MWt. In the next few months, steam is to be channeled from the reactor into a turbine to generate the first electricity to come from an Indian breeder reactor. As the core is expanded, the reactor power will be raised to its full design capacity.

The reactor uses an advanced uranium-plutonium mixed-carbide fuel developed indigenously. The fuel has special relevance in the Indian context in view of the need to realize short doubling time, the period necessary for the reactor to breed extra fuel for another reactor.

This experimental reactor has provided the insights, experience, and confidence needed to design a 500-MWe prototype fast breeder reactor. Design of this liquid-sodium–cooled reactor and its sodium-to-water steam generator has been a great and complex engineering challenge. Many difficult problems had to be solved in heat transfer, mass transfer, reactor control and instrumentation, materials (of both fuel and reactor structures), chemistry (of both the sodium coolant and the fuel), and safety analysis. The design specifies a number of passive safety features, such as large, negative, temperature and power coefficients and decay-heat removal through thermosiphon.

At present, technology for manufacture of the components and equipment needed for the reactor is under development, and construction of the reactor should begin shortly. Completion is planned for the 2007 time frame, after which a series of these reactors would be built all over the country.

India's nuclear power stations

Name and location	MWe (per reactor)	Construction stage	Operation		Constructor	Architect engineer	Reactor supplier (a)	Generator supplier
			Initial criticality	Commercial start				
Tarapur 1 Tarapur, Maharashtra	160	100%	2/69	10/69	Bechtel Corp. (U.S.)	GE and Bechtel	GE	GE
Tarapur 2								
Tarapur 3	470	0%	2/00	8/00	Nuclear Power Corp. of India Ltd. (NPCIL), others	Utility (b) and NPCIL	Utility, others	Bharat Heavy Electricals Ltd.
Tarapur 4			11/00	5/01				
Rajasthan 1 Kota, Rajasthan	207	100%	8/72	12/73	NPCIL, Hindustan Construction Co. (HCC)	AECL and MECO (Canada)	GE Canada, others	EEC (Canada)
Rajasthan 2			10/80	4/81			Larson & Toubro (India), others	
Rajasthan 3	220	31%	11/96	5/97	NPCIL, others	Utility and NPCIL	Utility, others	Bharat Heavy Electricals Ltd.
Rajasthan 4			5/97	11/97				
Madras 1 Kalpakkam, Tamil Nadu	220	100%	7/83	1/84	NPCIL, EEC			
Madras 2			8/85	3/86				
Narora 1 Narora, Uttar Pradesh	220	100%	3/89	1/91	NPCIL, HCC			
Narora 2			10/91	4/92				
Kakrapar 1 Kakrapar, Gujarat	220	100%	9/92	5/93	NPCIL, HCC			
Kakrapar 2		75%	4/93	1993				
Kaiga 1, Kaiga, Karnataka	220	40%	6/96	12/96	NPCIL, others			
Kaiga 2			12/96	6/97				

AECL = Atomic Energy of Canada Ltd.; EEC = English Electric Co., Canada; GE = General Electric Co., U.S.; MECO = Montreal Engineering Co., Canada.

(a) Tarapur 1 and 2 are boiling-water reactors; all the rest are pressurized heavy-water reactors.

Source: *Nuclear News*, September 1993; additional information from *Nuclear News* staff

Although reuse of radionuclides in breeder reactors should extend India's reserves by a factor of 80, the subcontinent's need for power is so great that still other sources must be developed to meet longer-term needs. A sustained R&D program has therefore been pursued on all aspects of thorium utilization. The centerpiece of this effort is a small reactor in Kalpakkam, called the Kalpakkam Mini Reactor, or "Kamini" (which happens to be a Hindi word loosely translating as "adorable woman").

UNIQUE REACTOR. The theory and practical aspects of thorium utilization have been studied and considered in the United States, France, and other countries; but the 30-kWt Kamini is the first and only reactor ever built actually to operate in this exotic fuel cycle. The Indian program embraces the entire cycle, from irradiation of the thorium-232, through reprocessing to recover uranium-233 and fabrication of the U-233 fuel, to design of a reactor for the U-233 and Th-232 fuels.

Still other aspects of the fuel cycle are being explored. Recently, thorium, rather than the usual depleted uranium, was used in the first PHWR at Kakrapar for initial power flattening, an exercise necessary for bringing a new reactor core up to full power. Work in this area will continue.

In addition, a start has been made on designing an advanced, heavy-water reactor based on the thorium-uranium blanket core driven by mixed-oxide–fueled seed regions. The reactor will be self-sufficient in U-233 and generate about 75–80 percent of its power from thorium, keeping use of plutonium to a minimum.

Meanwhile, implementation is under way of the modifications necessary for the introduction of mixed-oxide fuel in the reactors of the Tarapur Atomic Power Station, to sustain their operation.

India's nuclear electric program in general and its breeder-reactor projects in particular bear ample witness to the country's self-reliance policies. Research in this area has nurtured robust and indigenous problem-solving capabilities, and helped the country move toward its goals of energy security and self-sufficiency.

REPROCESSING REQUIREMENT. Certainly, in India's special case, the need for adequate energy supplies points to the necessity of reprocessing spent fuel and the recycling of plutonium and later uranium-233 in breeder reactors to fully exploit the fuels' energy potential. As developing countries—where most of the world's people live—become more electrified, energy policies must be formulated that respond not only to people's needs but also to the environmental impact of succeeding generations of technology.

India owes its accomplishments in nuclear science and technology to a large and diverse establishment, but a big share of the credit must go to its four research centers. The Bhaba Atomic Research Centre at Trombay (near Bombay on the west coast) is the mother institution. BARC, as it is known, serves R&D in many fields, ranging from the basic sciences to several applied disciplines, including materials research, electronics, and engineering. It also caters to the R&D needs of the thermal-reactor–based power program, the production and application of isotopes, and health and safety issues in nuclear science. The center also has the technology-development infrastructure needed for instrumentation support.

The Indira Gandhi Centre for Atomic Research, located in Kalpakkam, focuses mainly on the development of fast-breeder technology. It also has extensive programs in metallurgy, materials science, radiochemistry, reprocessing, and safety. As for the other two laboratories, the Variable Energy Cyclotron Centre promotes accelerator-based research, and the Centre for Advanced Technology concentrates on developing laser and accelerator technologies.

A number of industrial units have also been set up to cover the whole range of the fuel cycle. For example, the Nuclear Power Corp. of India Ltd. designs, constructs, and operates nuclear power reactors. The Heavy Water Board designs, constructs, and operates the equipment necessary to produce the heavy water that moderates the PHWRs. Obviously, all this work is aimed at producing atomic energy, but many of its fruits find applications elsewhere.

One such area of attention has been superconductive materials, including multifilamentary niobium titanium wires. Researchers are developing high-current–carrying conductors for cables as part of the accelerator program (an early use is expected to be in an accelerator's high-power magnets).

Other beneficiaries of the nuclear program have been the medical, agricultural, and food-preservation industries, all crucial to India's industrial aspirations. BARC's two large reactors at Trombay form a large base for the production of isotopes, and extensive facilities have been set up for processing the isotopes and converting them to forms suitable for assorted applications.

A recently convened Board of Radiation and Isotope Technology is active in expanding radiation and isotope use on a commercial scale. The application of isotopes to diagnosis and therapy today spans preparations based on iodine-131 and phosphorus-32, along with other labeled compounds. In addition, several technetium-99 generators are playing an important role in nuclear medicine. Radio-immunoassay kits are routinely being made available for the estimation of a spectrum of biological agents like hormones, vitamins, drugs, and viral proteins in body fluids, for early diagnosis of disease.

Intense cobalt-60 sources ranging from 3000 to 10 000 curies, encapsulated at BARC, are being used therapeutically in 62 cities in the country. These units treat between 1.5 million and 2 million cases per year, including about 60 000 new patients admitted annually to cancer hospitals across India. Radiation is also being used commercially to sterilize medical products at Isomed in Trombay, Rashimi in Bangalore, and at the Sri Ram Medical Institute in New Delhi.

Industrial applications are numerous. Among those commercialized are radiography and the use of tracers and sealed sources for process control and diagnosis. A sewage-sludge hygienization plant with a 150 000-curie cobalt source sanitizes half the sewage of the city of Baroda. Other radiation-processing applications include vulcanization of natural rubber latex, and cross-linking of polymers for cables and sleeves.

India's energy resources

		Energy potential, BTCE (a)	Utilization: Maximum capacity, GWe	Utilization: Years
Nonrenewable	Oil	0.6	N.A.	N.A.
	Gas	1.5	N.A.	N.A.
	Coal	150	500	122
	Uranium (once through)	1.2	15	32
	Uranium (recycled in breeders)	100	350	116
	Thorium	600	1000	244
Renewable	Hydro		160	
	Biomass		48 (b)	
	Wind		4 (c)	
	Solar	Expensive, diurnal, and seasonal		

(a) In billion tons of coal equivalent (BTCE).
(b) Assumes 20 percent of all waste land is used for energy plantation.
(c) Maximum capacity is 20 GWe with a plant load factor of 15–20 percent.

India's energy resources include substantial known reserves of coal and thorium, which could see the country through for centuries. The middle column indicates the amount of electrical capacity that could be comfortably sustained by the known reserves of each fuel. The rightmost column, indicating the years remaining, has been calculated using the first two columns and by assuming a 70 percent load (capacity) factor. Another assumption was an energy conversion factor whereby 3.5 billion tonnes of coal equivalent are required for 1 terawatt-year of electric energy

Department of Atomic Energy, Government of India

Heavy water, used to moderate and cool the cores of India's indigenously developed reactors, is produced at a plant in Manugum. Fueled with easily produced natural uranium, India's pressurized heavy-water reactors are based on the design of the Canadian Deuterium (Candu) reactor.

Big strides have been made with nuclear applications in agricultural research, too. Evolving high-yielding varieties of plants through radiation-induced mutations and the use of radiotracer techniques to study fertilizer and pesticide uptake are two research thrusts of interest. So far, over a dozen plant varieties have been created through mutation and a program of systematic breeding. These include four varieties of groundnut, two each of pigeonpea, blackgram, greengram, and mustard, and one each of rice and jute. Released for commercial cultivation, they are now growing on several hundred thousand hectares. The main objective has been development of high-yielding plants, but other features being sought are early or late maturation, larger pod size, and resistance to biotic and antibiotic stresses.

Use of radiation for food preservation is another of BARC's activities. So far, clearance has been obtained for the irradiation of spices, frozen sea foods, and onion. Simultaneously, the construction of radiation-processing plants has been undertaken.

India's atomic program has come of age. The efforts are resilient enough to meet the challenges that arise, and a large, multidisciplinary pool of technical and scientific workers ensures its continuing contribution to national development. While the program has many achievements to its credit, there are many more yet to come.

R. Chidambaram is chairman of the Atomic Energy Commission, the Government agency that plans, coordinates, and oversees all nuclear activities in India. Anil Kakodkar is director of the Bhabha Atomic Research Centre's Reactor Design and Development Group, and Placid Rodriguez is director of the commission's Indira Gandhi Centre for Atomic Research, in Kalpakkam.

Aerospace technologies: a terrestrial focus

In 1963, a rousing and historic year of early manned space flights by the United States and the then Soviet Union, another space program was getting off to a modest but auspicious start in a fishing village near the southern tip of India. On Nov. 21 of that year, a two-stage sounding rocket called Nike-Apache was launched from Thumba, near the town of Trivandrum and the earth's magnetic equator. The rocket, carrying a sodium-vapor release payload weighing 23.3 kg, reached an altitude of 207.6 kilometers. India had taken the first step of its journey into space.

K. Kasturirangan
Indian Space Research Organization

A national space program was formally organized some time later. In 1972, the Indian government set up its Space Commission for formulating policies and a Department of Space and Indian Space Research Organization, the commission's technical and scientific arm, for implementing those policies. The space program was given the well-defined objective of applying space technology to communications, meteorology, and resources management—goals that have guided its growth into a diversified effort with a list of capabilities and achievements unmatched elsewhere in the developing world.

The grassroots orientation of the program was established early on, with a series of experiments in the mid- and late 1970s in satellite television, telecommunications, and remote sensing. A dual-track effort was sustained: projects on non-Indian platforms were carried out in parallel with development of India's own satellites.

Through the use of the United States' ATS-6 satellite, for example, a series of educational programs on health, family planning, agriculture, and the like were broadcast to over 2500 Indian villages in 1975–76. The short-lived project was part of the Satellite Instructional Television Experiment and stands to this day as one of the most important sociological experiments done in India using aerospace technology. A similar Satellite Telecommunication Experimental Project used the French-German Symphonie satellite during 1977–79, and remote-sensing experiments used aircraft-mounted cameras

or data from the U.S. Landsat satellites. All these applications demonstrated the utility of space-based systems for a large, developing country like India.

In the meantime, space hardware was being developed with an eye to founding a self-reliant and self-sustaining program. Named after an Indian astronomer of antiquity, Aryabhata, India's very first satellite, was launched on April 19, 1975, and taught the country its first lessons in operating a satellite in orbit. It was followed by two experimental remote-sensing satellites named after the ancient Indian mathematician and astronomer, Bhaskara (which also means "sun" in Hindi). The two Bhaskara satellites were launched, like Aryabhata, on Soviet Intercosmos rockets, in June 1979 and November 1981.

INSAT IN ORBIT. While valuable in their own right, these and similar experiments can be seen as laying the foundation for the momentous Indian National Satellite (Insat) program, which continues to this day. Besides being, in many ways, the mainstay of the Indian space program, Insat has been one of the most successful technological initiatives in Indian history.

Admittedly, the first and third of these multipurpose geostationary satellites failed in orbit. But the second, launched in August 1983 aboard the U.S. space shuttle Challenger, and the fourth, which is still in service, opened up a new era for telecommunications, TV broadcast, and meteorological services in India. This first generation of Insat satellites were built by Ford Aerospace (now Loral Space Systems) in Palo Alto, Calif. They carry 12 C-band telecommunications transponders, two high-power S-band TV broadcast transponders, a very high-resolution radiometer for meteorological earth imaging, and a data relay transponder. This last instrument relays meteorological, hydrological, and oceanographic data from unattended land and ocean-based platforms.

The second Insat generation was designed and built within India. Insat-2A and -2B were launched on July 10, 1992, and July 23, 1993, on Ariane vehicles. Besides the suite carried by the first generation, they have six extended C-band telecommunications transponders, an even higher-resolution radiometer (2 km in the visible spectrum and 8 km in the infrared), and a transponder for satellite-aided search and rescue operations.

Three more of these second-generation satellites are being built. Insat-2C and -2D, incorporating the Ku-band transponder in place of meteorological payloads, are scheduled for launch in 1995 and 1996, while Insat-2E, with an improved meteorological payload, is to be launched in 1997. All the Insats are controlled and operated from a master control facility in Hassan, in the state of Karnataka in southern India.

The Insats have revolutionized communications in India, enabling, for example, remote villages and various island territories to be brought into the national telecommunication network. The Insat system now covers 161 routes, 140 earth stations, and more than a thousand very small-aperture terminals (VSATs).

Besides the usual administrative, business, computer communications, and information-exchange applications, Insat's wide geographic reach has made several specialized services possible, such as news and facsimile transmission and emergency communications for relief operations after a disaster. Its uses range from telegraphy in the mountainous regions of northeastern India to spread-spectrum data communications over the Government-sponsored National Information Centre Network (Nicnet) between district headquarters, state capitals, and central Government departments. Similar uses are too numerous to include here.

Because it is the only geostationary satellite above the Indian Ocean to have meteorological-imaging capabilities, Insat has become important for both local and worldwide weather monitoring. Normally the satellite's very high-resolution radiometers make images every half hour—or more often during cyclones and hurricanes. These complement data from over a hundred remote, unattended meteorological data-collection platforms, markedly improving the quality of forecasts.

A novel use of Insat has been in the implementation of the unique, unattended, locale-specific Disaster Warning System, with over 100 receivers installed along India's cyclone-prone east coast. Since its commissioning in 1987, the system has become a vital means of softening the impact of disasters: in May 1990 it helped save over 170 000 people by timely evacuation before a devastating cyclone hit.

Nor is this Insat's only life-saving feature; a satellite-aided search-and-rescue transponder has been incorporated on the Insat-2s to issue instantaneous emergency alerts in the Indian Ocean region. It is compatible with the international Cospar-Sarsat system, under which two local user terminals, at Bangalore and Lucknow, have been established.

Such vital uses notwithstanding, Insat's most dramatic impact has been in the rapid expansion of India's TV and radio networks. About 550 TV transmitters today reach over three-quarters of the population, and more than 100 000 direct-reception sets have been

Indian Space Research Organization

The year-long Satellite Instructional Television Experiment, begun in August 1975, brought educational television programs on health, family planning, agriculture, and the like to some 2500 Indian villages. The project made use of the United States' ATS-6 satellite, and stands to this day as one of the most important sociological experiments done in India using aerospace technology.

installed, in both urban and rural areas. In addition, Insat is used to network India's 108 radio stations.

Thirteen regional TV channels carry programs in all the principal Indian languages. Transportable earth stations have enabled TV coverage of holiday celebrations, sporting events, elections and other news, and cultural festivals in all parts of the country. Indigenously developed satellite news-gathering vehicles, with umbrella antennas that can fold shut, are helping to streamline dissemination of news.

Much of this broadcast material is educational in nature, with about 100 hours of programming being transmitted every month to more than 4000 schools and colleges. Facilities for producing educational programs have been established at national and state levels. Demonstrations of interactive educational TV, for training teachers, educating farmers, and continuing the education of industrial workers, have been conducted. Planned for launch before the turn of the century is a dedicated satellite for education, to be called Gramsat (*gram* is Hindi for "village").

REMOTE SENSING. Although sometimes overshadowed by the multipurpose and high-flying Insats, a separate satellite fleet for the indispensable task of remote sensing also looks down on the subcontinent and beyond. These Indian Remote Sensing (IRS) satellites are operated under the umbrella of the National Natural Resources Management System, which is supervised by the Department of Space. Their highly diverse, critical tasks include the estimation of agricultural crop area and yield, drought warning and assessment, flood control and damage assessment, land use and land-cover mapping for agro-climatic planning, wasteland management, and water resources management. They also help in the surveying and management of ocean and marine resources, urban development, mineral prospecting, forestry, and other functions.

At present, two remote-sensing satellites, IRS-1A and -1B, are in operation, having been launched on Soviet Vostok rockets in March 1988 and August 1991. Their payloads include two advanced imaging sensors, known as linear imaging self-scanners, with resolutions of 36.25 and 72.5 meters and swaths of 145 and 148 km, respectively. Their cameras can operate in four spectral bands in the range of 450–860 nanometers.

The IRS satellites are in polar sun-synchronous orbits at a height of 904 km and with an orbital period of 103 minutes. They return to their original orbital trace every 22 days, enabling repeated collection of data over the same place and local time.

The second generation of IRS satellites, the -1C and -1D models, incorporate an improved camera that will operate in three visible and near-infrared spectral bands; its ground resolution is 20 meters in the visible band and 70 meters in the infrared. Another camera functions panchromatically, with resolution of 10 meters, and a wide-field sensor operating in visible and near-infrared, with resolution of 188 meters and a swath of 774 km. IRS-1C is to be launched sometime this year or next and -1D, during 1996-97.

Indian Space Research Organization

The Polar Satellite Launch Vehicle was launched on its first developmental flight last Sept. 20. It failed to place the remote-sensing satellite it was carrying into the intended orbit, but it did verify the operation of almost all of the rocket's subsystems. The second developmental flight of the 280-tonne, 44-meter-tall rocket is scheduled for later this year, pending analysis of the data from the first flight and any necessary modifications.

The IRS satellites are tracked and monitored by a control center in Bangalore, along with ground stations at Lucknow and Mauritius, off Madagascar in the Indian Ocean. Data is received at a National Remote Sensing Agency station at Shadnagar, near Hyderabad, and processing and distribution is carried out by the same agency at facilities in Hyderabad.

Agriculture has the highest-priority use of this data. More than three-quarters of India's population depends for its livelihood on the land. Remote sensing is now used routinely to predict areas and yields of crops like wheat, rice, and sorghum; oil seeds such as groundnut and mustard; and commercial crops such as cotton, mulberry, tea, and tobacco. Harvests have been predicted with accuracies of up to 90 percent for vast areas covered by a single crop. Crop stress is also monitored by using satellite data for early warning of drought. Fortnightly bulletins are issued to assist the authorities and agricultural resource planners in dealing with situations on a near real-time basis. Under development are methodologies for applying remote sensing to the timely detection of pests and disease.

A national project was recently completed using remote-sensing satellite data to generate information on land use and land cover for the entire country. The data will serve areal planning, management and utilization of land for agriculture, forestry, urban and industrial environments, and so on. Accurate information on agricultural land use, including cropping patterns, fallow and grazing lands, and surface water, has been gleaned through the project.

Forest maps, too, have been prepared showing that India's closed forest cover during 1975–85 had fallen from 14 to only 11 percent of the country's total land area. In response, India's Forest Survey is now mapping all of the country's forests every two years using satellite data. In addition, new techniques for estimating the density and volume of forests are being developed.

Mankind's encroachment has also left India with huge tracts of land now believed unusable. About 20 percent of India's land area is held to be wasteland because of excessive use of fertilizers, faulty irrigation, excessively prolonged agriculture, use of slash-and-burn clearance techniques, and the spread of desert. Countrywide mapping of wasteland by means of space images identified 13 distinct wasteland categories at the village level. It has since been found that almost half of these wastelands—some 25 million hectares in all—could be reclaimed with appropriate agricultural practices.

WATER MANAGEMENT. Satellite images are routinely used to help in managing water resources. They assist in, for example, the prioritization of watersheds, monitoring of surface water bodies, studies of rainfall runoff, and irrigation scheduling. Linking satellite data to other information on rainfall, soil types, slopes, and land-use patterns has made it possible to estimate erosion rates, plan erosion control measures, and identify sites for water harvesting.

Hydro-geomorphological maps generated with satellite data are in wide use for locating borewells. All of India's territory has been mapped to identify aquifers capable of providing people with drinkable water. Some 200 000 wells have been located, and statistics show a 90 percent success rate for techniques using satellite data—more than twice the rate achieved without this data.

Models have been developed for the Himalayan river basins to map the changing seasonal snow cover and to estimate runoff from the snow-melt during the summer. These estimates, made three to four months

before runoff with an accuracy better than ±3 percent, are improving the use of water for electric power generation and irrigation. Remotely sensed data serve also to identify and prioritize areas prone to erosion in various watersheds, as well as providing inputs for projects for removing silt. Seasonal changes in the volume of water in the larger reservoirs and in agricultural crops are being studied to draw up plans for the best use of water.

A similar satellite function is to supply real-time information on heavily flooded areas, for the purpose of rehabilitation. Quantitative estimates of the damage to infrastructure and crops are also provided. Monitoring the patterns of inundation year after year has helped to identify safer areas in zones at risk, both for the sake of rehabilitation and long-term flood control.

Other uses of satellite data have been in mineral exploration and urban-area and coastal-resource planning. Digital analysis of data has yielded land-use and urban-sprawl maps of the big Indian cities, invaluable for siting industries, housing, and infrastructure as these cities expand. Likewise, maps of the country's entire coastline have assisted in identifying brackish water and bodies of water suitable for inland fisheries. Methodologies have been developed for identifying areas rich in fish: from estimates of the density of phytoplankton and the distribution of ocean temperatures, forecasts of the whereabouts of schools of fish are made and broadcast to guide fisherman.

As valuable as such applications are by themselves, their utility soars when tied in with a holistic development program. This is the philosophy behind the recently established Integrated Mission for Sustainable Development, under which 157 districts have been identified and implementation begun in six districts. In this program, remotely sensed data is used to prepare maps showing the land as is: surface bodies of water, zones with ground-water potential, and areas where the ground water needs recharging, as well as types of soil (degrees of salinity, alkalinity, and erosion), existing land use, distribution of waste land, and so on.

Then, when space-based and meteorological data are combined with socioeconomic factors, integrated land and water resource maps are prepared. These show micro-level information and highlight priority areas for agricultural development, fuel and fodder development, soil conservation and reforestation, and the like. The overall goal is a package of practices and strategies for addressing local problems and leading to sustainable development.

UP, UP, AND AWAY. Of course, before we can aspire to such heights, we must be able to reach earth orbit. In keeping with its longstanding emphasis on self-sufficiency, India has an ambitious launch-vehicle program designed to send its own remote-sensing and communications satellites into orbit.

India's efforts in this area began with the launch in July 1980 of the SLV-3 booster, which placed a 40-kg Rohini satellite into a near-earth orbit. The 22.7-meter-tall SLV-3 was an all-solid-fuel four-stage vehicle with a lift-off weight of 17 metric tons. Two more launches of SLV-3s were conducted in May 1981 and April 1983, both times carrying Rohini satellites equipped with solid-state imaging sensors.

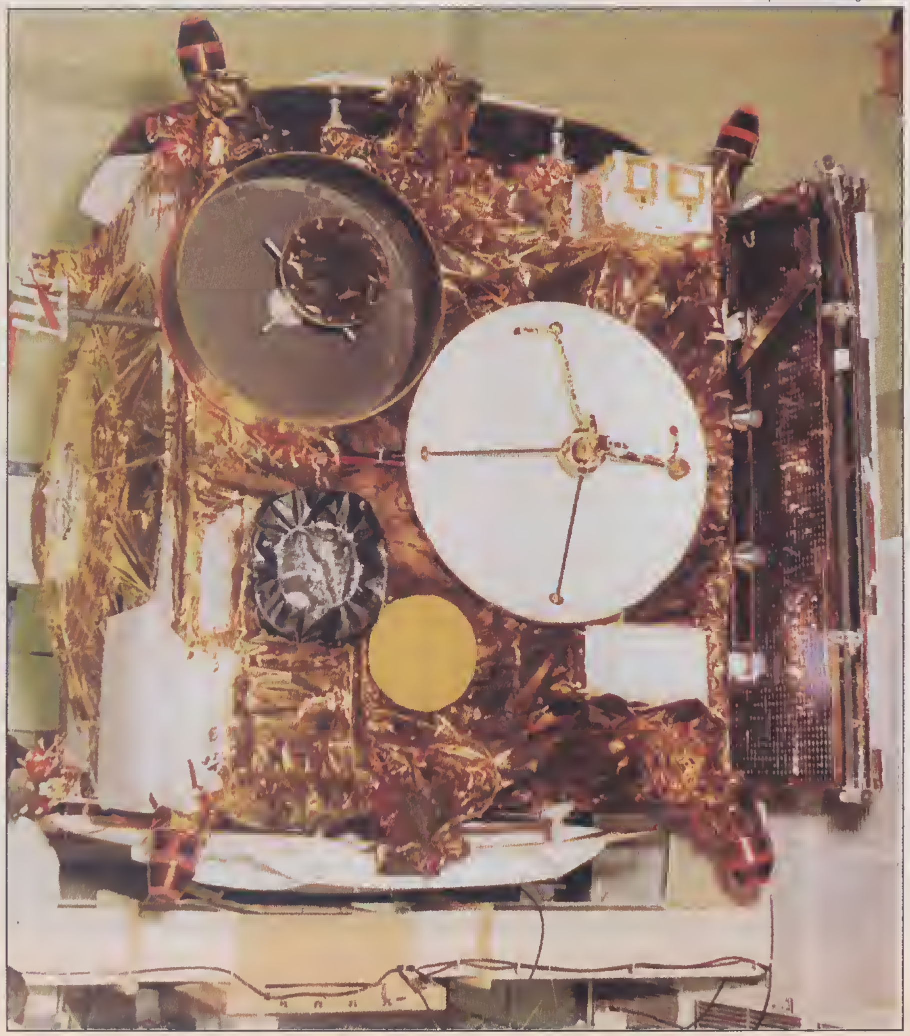
The next vehicle, known as the Augmented Satellite Launch Vehicle (ASLV), was successfully launched from Sriharikota Range on May 20, 1992. This was the vehicle's third developmental launch, and it injected a Stretched Rohini Satellite into a near-earth orbit. The vehicle is a five-stage, solid-propellant rocket capable of putting a 150-kg payload in near-circular orbits. It also led to the more advanced Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV).

The 280-tonne, 44-meter-tall PSLV can put a remote-sensing satellite in the 1000-kg class into a 900-km polar sun-synchronous orbit. The first of its four stages straps six motors derived from the SLV3 round a 125-tonne solid-propellant motor with a 2.8-meter diameter. The second stage, also 2.8 meters in diameter, is based on liquid-engine technology and uses 37.5 tonnes of propellant. The third and fourth stages are 7.2-tonne solid-propellant and 2.0-tonne liquid-propellant motors, respectively. The rocket is guided by a closed-loop system with onboard processing.

The first developmental flight of the PSLV took place last Sept. 20. Though it failed to place the IRS-1E it was carrying into the intended polar orbit, it did verify the functioning of almost all subsystems. The second such flight is scheduled for later this year, pending analysis of data from the first flight and modification based on that analysis.

Development of the three-stage GSLV is now under way. It is to be capable of launching 2500-kg-class communication satellites into geostationary transfer orbit. It is derived from the PSLV in that it replaces the six solid-propellant strap-on motors of the earlier vehicle's first stage with four liquid-propellant ones derived from that vehicle's second stage; it also substitutes a single cryogenic stage for the upper two stages of the

Indian Space Research Organization



The Insat series of multipurpose satellites opened up a new era for telecommunications, TV broadcast, and meteorological services in India. The second generation of these satellites, including the Insat-2A pictured here, was designed and built within India. Insat-2A was launched on July 10, 1992, on a European Ariane vehicle. This generation improved on the first with additional telecommunications transponders, a higher-resolution radiometer, and a transponder for satellite-aided search and rescue operations. Three more of these second-generation satellites are being built.

PSLV. The first developmental flight is planned for the 1995–96 time frame.

HIGH-TECH INDUSTRY. The exacting requirements of India's space program have demanded the participation of industry on a large scale, so India has from the very beginning striven to involve its businesses in the endeavor. The volume of orders has grown from around 100 million rupees during the 1970s to over 7 billion rupees during 1985–90. Of late, research, design, and development engineering contracts have also been awarded to elite Indian industries for complex subsystems and projects. In addition, over 200 technologies developed under the space program have been transferred to industries all over the country.

With all this diffusion of tasks, skills, techniques, and technologies, a vibrant and dynamic space industry has emerged that cuts across small, medium-sized, and large concerns in both public and private sectors. The program has become an integral part of Indian society, with benefits extending over several areas of endeavor.

Our challenge in this decade will be not only to consolidate benefits accrued so far, but to set out on new pathways. For two decades, space activity in India has focused on benefiting the populace at large and it will continue to do so. The pivotal part it has played in dealing with the major national tasks, and in particular its emphasis on transforming the lives of those living in remote areas and bringing them into the mainstream of the nation, make the program unique, and perhaps a model for other developing countries perched on the threshold of space.

K. Kasturirangan is director of the Indian Space Research Organization's Satellite Centre in Bangalore and a member of the Space Commission, India's policy-making body for aerospace activities. He has held various posts in the satellite program, including project director for the Bhaskara and IRS-1A satellites. He is chairman of India's Advisory Committee on Space Sciences and of Cospar's panel on Space Research in Developing Countries.

Telecommunications: at least a phone in every village

India is home to more than 850 million people, but to very few telephones. For every thousand inhabitants, it has only about eight phones, versus an average of 100 in the developing world, and 600 in developed countries.

In round figures, the country has 7 million lines. But only 14 percent of these are in rural areas, where 75 percent of India's population lives. There is a waiting list of nearly 3 million would-be subscribers, of which, again, all but 14 percent are from the metropolitan and urban areas. During the last fiscal year, the number of lines grew by about 17 percent, and India is aiming to establish a network with 20 million telephone lines by the year 2000. By then, if all goes well, there will be at least one phone in each of the country's nearly 370 000 villages.

To understand the status and aspirations of Indian telecommunications, it is necessary to turn back to the early 1980s, a time of extraordinary ferment. In 1983, while the drama of AT&T Co.'s divestiture was coming to a conclusion in the United States, the first steps toward a digital network were being taken in India with the transfer of Alcatel's E10B switching technology to Indian Telephone Industries (ITI), the Government-owned and managed telecommunications company.

An experimental analog electronic exchange, developed by the Government's Telecommunications Research Centre and fabricated by ITI and Bharat Electronics Ltd., was used for about a year, serving some 200 subscribers in Delhi. But the first full-scale program to develop commercial, indigenously designed switches came later, in the early 1980s, at ITI. Three switches were developed: the ESAX, based on pulse-amplitude modulation and quickly discontinued; and the ILT and MILT, digital models with capacities ranging from 64 to 2028 ports, which are connection points for trunks and so on.

Bishnu D. Pradhan
Centre for Development of Telematics

The drive toward digitization moved into high gear in August 1984, when the Centre for Development of Telematics was created with funding from the Government's departments of Electronics and Telecommunications (the latter operates the nationwide telephone network). C-DOT, as it is known, was given a formidable mission: to design, in three years, a state-of-the-art digital system capable of switching 40 000 lines and ultimately handling 800 000 attempts at calls during busy hours. Those capabilities would put it on a par with such premier models as AT&T's 5ESS, Alcatel's OCB-283, Siemens' EWSD, Ericsson's AXE, and Fujitsu's Fetex 150. C-DOT was also given the task of creating a center of excellence in telecommunications and transferring its technology to a manufacturing and vending base that as yet did not exist outside ITI.

As of this writing, less than 10 years after its formation, C-DOT has developed a family of switching products and is a few months from installing its first production version of the 40 000-line switch in the southern city of Bangalore. Today, there are just over 2 million lines in India served by two earlier C-DOT–designed switch models—1 100 000 switched by the Rural Automatic Exchange, and 900 000 by the Main Automatic Exchange.

In addition, some 300 000 lines are served by a C-DOT–designed private automatic branch exchange (PABX), the agency's first product, whose prototype was completed in 1985. After the PABX went into widespread manufacture, per-line costs for PABXs declined by almost a half from the days when ITI was the sole source of this technology.

All three of C-DOT's switch types were based on the same digital system, a flexible and modular design. The hardware relied on Motorola 68000 and Rockwell 6502 microprocessors, then the state of the art. The software made use of both standard Unix and a proprietary, real-time operating system.

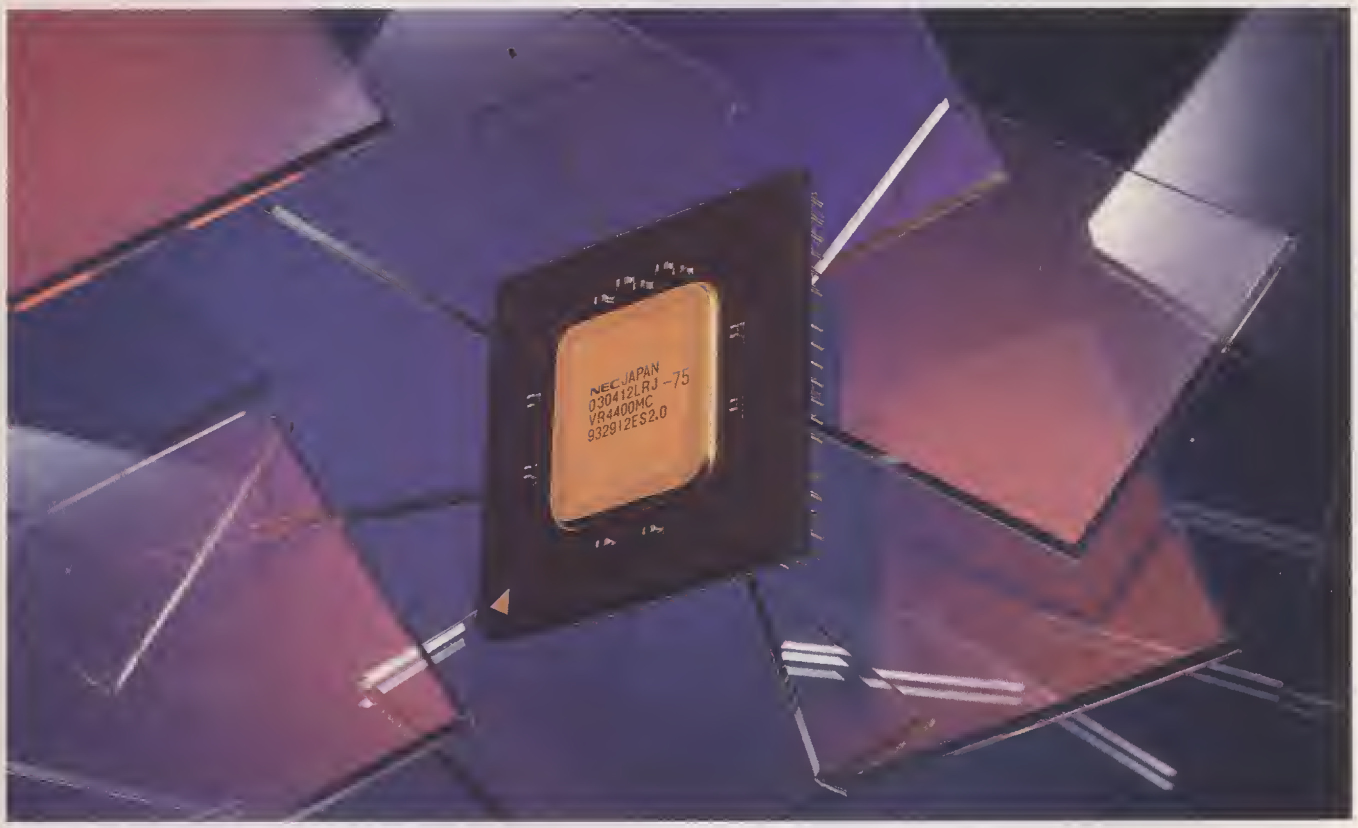
The second product based on this switching system was the 128-port Rural Automatic Exchange. With its huge rural population, served mainly (if at all) by antiquated electromechanical exchanges, India's need for a reliable digital switch was great. But such a switch had to be extremely rugged to keep working at temperatures as high as 45 ° or 50 °C and at relative humidities well above 90 percent.

Heat and humidity, moreover, were but two of the extremes confronting system designers. Indian villages often are dusty, have commercial power supplies of very poor quality, and are infested with snakes and rodents given to chewing on wires and cables. They also lack trained manpower, so that the exchanges had to have extensive built-in diagnostics and redundancies, as well as remote-monitoring features.

The Rural Automatic Exchange is, in fact, C-DOT's original digital switching system equipped to survive these more exacting conditions and environments. The first one was cut over on July 21, 1986, in the village of Kittur in the southern state of Karnataka. As with the earlier PABX, C-DOT offered the technology to dozens of manufacturers in exchange for a fee and royalties on sales. The initial response was overwhelming, and the production rate of the switch soon reached about one a day, with some 30 Indian manufacturers turning them out not only for the domestic market but for export to Russia and several developing countries as well. On the basis of this success, a 256-port version was designed, with features enabling it to be configured as a terminal switch, a transit switch, or a hybrid of the two. The first of these was installed on March 31, 1991, in the village of Anekal, also in Karnataka.

The exchange's economic and social effects on rural India were profound. For the first time, many villages became connected to the rest of India and, where transmission systems allowed, to the world. This access brought about far-reaching changes in the agricultural and economic activities in these villages. For

(Continued on p. 46)



THE VR4400™ RISC PROCESSOR: IDEAL PLATFORM FOR WINDOWS NT.™

The Windows NT operating system has extraordinary potential. It offers the power, reliability and openness to launch a new era in business and high-end personal computing.

But this potential can only be realized if microprocessors provide the superior performance which Windows NT demands.

NEC's response to the challenge is the VR4400 — a 64-bit processor based on MIPS® RISC architecture. Running at 150MHz internally, it delivers 94 SPECint92 and 105 SPECfp92. Third-party benchmarks indicate that the VR4400 runs Windows NT nearly twice as fast as Pentium.™

The VR4400 comes in two versions. The standard VR4400PC features an on-chip floating point unit and separate 16K-byte instruction and data cache. The high-end VR4400MC supports a secondary cache of up to 4M bytes and a multiprocessing system, in addition to offering all standard functions. Three internal speeds are available for both versions — 100, 133 and 150MHz.

NEC's 64-bit RISC processor is already driving the world's most powerful workstation. While providing excellent price/performance, the VR4400 allows users to run existing DOS and Windows 3.1 applications software under the new NT operating system.

In addition to microprocessors, NEC also offers chip sets, advanced DRAMs and TFT color LCD screens to support the next generation of personal computing.

All trademarks are property of their respective holders.

VR4200™ RUNS WINDOWS NT FOR NOTEBOOK PCs.

NEC has the industry's broadest line of 32- and 64-bit RISC microprocessors. Our latest offering is the 64-bit VR4200, which delivers VR4000 performance at 1/5th the cost.

With performance of 55 SPECint92 and 30 SPECfp92, the VR4200 is powerful enough to build desktop capabilities into notebook computers running Windows NT.

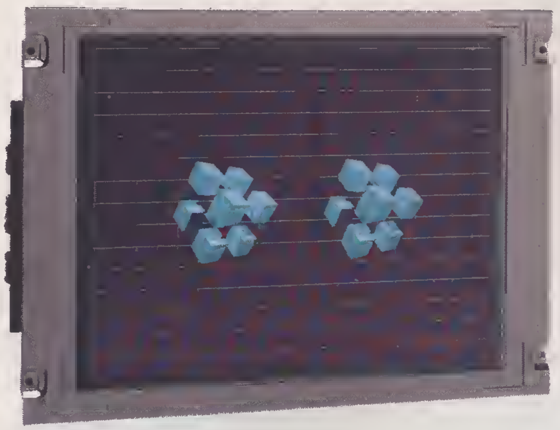
The 80MHz VR4200 also offers a cost-effective RISC solution for designers of low-end workstations, X-terminals and diverse embedded applications.

The VR4200 incorporates 16K-byte instruction cache and 8K-byte data cache. Implemented with a 0.6-micron CMOS process, it runs on 3.3V and consumes only 1.5W. The VR4200 is available in a low-cost 208-pin plastic QFP or 179-pin ceramic PGA.

The VR4200 was developed jointly with MIPS Technologies, Inc.

TFT ACTIVE-MATRIX COLOR LCDs.

Liquid crystal displays (LCDs) are becoming more brilliant, colorful and versatile. NEC believes the greatest advances will be made in thin-film-transistor (TFT), active-matrix color LCDs. We're committed to TFT LCDs because they give users clear advantages in display quality and performance.



For notebook PCs, we're mass-producing a 24cm (9.4-inch) display which offers an optimum balance between brightness, power consumption, size and weight. It displays 4,096 colors with 640 x 480 pixels, consumes 8W, measures 12.5mm deep and weighs 680g.
24cm displays were pioneered by NEC and have now become the de facto standard for notebook PCs.

For handheld terminals and measuring equipment, we offer a high-resolution 17cm (6.5-inch) display. It features 640 x 480 pixels arrayed at a 0.207mm pitch on a display area about half the size of 24cm model.
The 17cm screen displays 4,096 colors, consumes 5W and weighs 360g.
It has already been designed into high-end measuring equipment such as FFT analyzers.

16M SYNCHRONOUS DRAMs.

Microprocessor speeds are soaring while DRAM access speeds are not. To break the bottleneck, NEC is introducing a new species of ultra-fast DRAMs.

Operating at 100MHz external clock, our 16M Synchronous DRAMs eliminate CPU wait states.
PC designers gain a quantum leap in system speed and workstation designers save by eliminating costly cache SRAMs.

The new DRAMs provide a minimum cycle time of 10ns (100MHz). The maximum data transfer rate for a x16 device is 200M bytes/sec with a 3.3V power supply.
Our Synchronous DRAMs are designed with 3-stage pipeline architecture and fully meet JEDEC standards.

We offer a wide choice of 16M Synchronous DRAMs. Clock-speed versions are 66, 75, 83 and 100MHz. Bit organizations are x4, x8 and x16.

NEC

(Continued from p. 43)
example, diamond polishing—an important livelihood in some areas—became centered on villages with a telephone exchange. The availability of telephones also meant that produce could be marketed to buyers in distant parts of the country, altering sales patterns on a national scale. Farmers growing tomatoes near Kolar, in southern India, had been selling their produce in Bangalore, but when Kolar got an exchange, they found out that higher prices were being paid in Madras. Needless to say, that's where most of their produce starting going.

In a study of how these and other aspects of telecommunications affected the countryside, the socioeconomic benefits over the anticipated 15-year life of each rural automatic exchange were estimated at US $2300 per line. The study used a random sample of 32 installations and was carried out by the New Delhi–based National Council for Applied Economics Research.

The villages that got Rural Automatic Exchanges were chosen initially on the basis of how long the waiting lists of potential subscribers were. Later on, they were awarded to whichever villages were campaigning most vociferously. The switches quickly became a status symbol among the Indian villages that vied for them, and exchange operators and technicians, aware of the vital service they performed, developed a visible *esprit de corps.*

Nonetheless, erroneous information got around at times. For instance, in several sites I visited in the northeastern Himalayan mountains, near Nepal, large signs commanded visitors to remove their shoes before entering the exchange room [see photo, opposite top]—this in spite of the fact that the exchange had been designed to withstand threats much more menacing than a little dust. Many switches are sheltered only by a thatched hut, or are installed next to a cow stable, and are left unattended for days.

Like the PABX before it, the rural exchange also symbolized the further weakening of ITI's monopoly. At the same time, it and other C-DOT designs stimulated a rival program of switch design and development at ITI. While ITI continued producing the ILT and MILT switches, it also developed an application-specific integrated circuit for switching uses, a military version of one of its switches, and an 8000-port digital switch, the XD90. The first prototype of this switch is now undergoing design-verification trials in the Indian network.

TO THE MAX. Today, C-DOT finds itself on the verge of fulfilling its original mission, namely, to provide a state-of-the-art digital switch comparable to those offered by the big multinational communications firms. Development of this Main Automatic Exchange (MAX) was carried out in three stages. First, there was the MAX-M, built around the basic C-DOT switching module, and capable of handling 1500 lines. Then came the MAX-L, with up to 20 000 lines, and now the full potential of the design is expected to be realized shortly with the 40 000-line MAX-XL.

At present, about 1000 MAX-M exchanges have been produced and installed. About 75 MAX-Ls have been built, of which about two dozen have been connected to the network and are now operational. The first MAX-XL, manufactured by ITI, is now being installed in Bangalore and should go into service sometime around the middle of this year.

In keeping with its goal of ending ITI's monopoly by creating a nationwide industry for manufacturing telecommunication equipment, C-DOT has come up with a competitive strategy for technology transfer. The center at first was extremely liberal. Its PABX technology was made available to 40 manufacturers, some of whom had never even been in the electronics business before. However, only 30 or so of these original 40 manufacturers were selected to manufacture the rural switch, and only nine companies (including ITI) were initially awarded licenses to manufacture the MAX-M switches. Today, there are 22 manufacturers of the MAX-M, 10 of the L, and one (ITI) of the XL.

Manufacturing capacity for all the switching systems (including the PABX) is about 2 million lines per year, with workers working only one shift per day. Most importantly, however, most of the capital invested in this manufacture came from private companies—a big change from a decade ago, when such investment came entirely from the Government.

From the very beginning, C-DOT propounded a production philosophy that would maximize manual labor and minimize capital equipment. After all, India has a large labor force but limited financial resources for purchasing expensive manufacturing equipment. The process conceived by C-DOT therefore emphasizes assembly and test of components produced locally.

Since technical expertise is not common among factory workers, an extensive transfer of technology package was devised. It included design documentation and engineering, manufacturing, and quality-assurance packages. Design documentation covered system architecture (both hardware and software), circuit schematics, block, timing, and assembly diagrams, components lists, and so on. The engineering package had details on wiring, mechanical packaging, system assembly, and site engineering. The manufacturing package had capital goods specifications, supply sources, a bill of materials and components, factory requirements and layout, details on component, card, and subsystem testing, integration and validation procedures, and even packing and shipping details. Quality assurance covered standards in this regard and plans for meeting them.

Regular training programs and meetings are held between C-DOT's Transfer of Technology group and the manufacturers, to iron out production problems. C-DOT assists manufacturers through their first production unit, and carries out the quality assessment and the validation of the first systems, before the system is offered to the Government's Department of Telecommunications for final approval and certification. The Transfer of Technology group also provides manufacturers with all software updates and with replacements for hardware systems as they become obsolete.

HARD BARGAIN. Today, C-DOT-developed switches handle over a third of the Indian telecommunications network, or about 2.3

Glenn Zorpette

In India, state-of-the-art optical-fiber cable is laid the old-fashioned way. This route will connect Pune, a fast-growing technical and scientific enclave not far from Bombay, with the village of Narayongaon, where a radiotelescope is under construction—and near which this picture was taken.

A sign at the building housing the Rural Automatic Exchange in the village of Mirik, high up in the Himalayas, commands visitors to remove their shoes, even though the switch was built to withstand rigors far worse than dust. The switch is a smaller, rugged version of the 1500-line Main Automatic Exchange, shown below in the author's home town of Darjeeling.

Centre for Development of Telematics (photos)

million lines (including PABXes). Many have high hopes for the 40 000-line MAX-XL switch, but so urgent is the need for more switching capacity that the Department of Telecommunications has in recent years bought and installed switches from Fujitsu, Siemens, AT&T, Ericsson, and CIT-Alcatel. These giants had for years sought to enter the Indian market, but were barred from doing so by Government policies. Now, as part of its liberalization program, the Government has relaxed some import restrictions, making such sales possible.

Nonetheless, the availability of locally designed C-DOT technology, along with a large manufacturing base, enabled the Government to drive a harder bargain while negotiating for the large switches from the multinationals. The final per-line prices were all in the vicinity of $150, which almost certainly would have been higher in the absence of any local alternative. Several of the multinationals have set up joint ventures with local partners to manufacture their switches locally. Many of these local partners either own, or are associated with, C-DOT licensees who manufacture the MAX-L.

C-DOT's success in rural switching has meant and means a nice niche market not only in India, but potentially in any developing country with a rural population and a need for telecommunications. The center is now promoting the export of the Rural Automatic Exchange technology to other developing countries. So far, systems have been installed in Vietnam, Russia, Yemen, Nigeria, and Nepal.

Recently, C-DOT upgraded the rural exchange technology to support 10-channel digital radio, for point-to-point linking of the exchanges at very low cost. Also, a new system to mesh the exchange with time-division multiplexed radio is under test. The goal is a time-division, multiple-access, point-to-multipoint system for handling up to 64 remote stations, each with eight remote subscribers.

India's decade-long program to develop its own switching technology has paid rich dividends. The experience gained with the Main Automatic Exchange and other projects has bred a strong R&D organization capable of developing new generations of switches, and a diverse, indigenous manufacturing base. In less than a decade C-DOT has garnered a sizable share of the local telecommunication market, and its products are now beginning to succeed in the export market.

Liberalization, in short, while forcing Indian manufacturers to compete against multinationals with state-of-the-art technologies, is also opening up opportunities. Indian companies will continue working with the multinationals on joint development, not only as a way of leap-frogging into the state of the art, but to bring the country up to world standards in the availability and quality of its telecommunications.

Bishnu D. Pradhan (SM) is executive director of the Centre for Development of Telematics, an autonomous agency of the Government of India charged with developing telecommunications equipment. He was previously with the Tata Electric Companies, which he joined after earning his doctorate and working in the United States for eight years.

Electronics and defense: turning setbacks into successes

As the world's second-largest consumer market—much more populous even than the North American Free Trade area or the European Ecnomic Community—India's commercial potential in electronics is huge. From small beginnings in the late 1960s, the country's electronics industry has grown to a business that annually generates 120 billion rupees (about US $4 billion). In this bustling arena are about 100 Government-owned manufacturing plants, an estimated 470 large and medium-scale private companies, and more than 3000 small-scale production units, all private.

V. Prasad Kodali — Department of Electronics
Vasudev K. Aatre — Ministry of Defence

All in all, these businesses employ around 300 000 people, about 45 percent of whom are electrical engineers, scientists, and other technical professionals. The industry is spread out all over the country, with concentrations around Bangalore, Bombay, Delhi, and Hyderabad. Yet the total electronics production and the productivity per employee remain low [see table, p. 48].

The reasons for these production inade-

quacies are many. Electronics and automation are widely regarded as leading directly to unemployment, a distinct liability in a country where joblessness is pervasive. Also, products such as television receivers and telephones are still viewed as nonessential, even luxurious.

Furthermore, a protected domestic market, in conjunction with high import tariffs and other restrictions, has had the effect of keeping electronics, like most other Indian industries, out of global markets. The picture is, however, rapidly changing with the liberalization of economic and industrial policies over the last few years.

Another problem is the industry's skew toward equipment and finished products, which constitute more than 80 percent of the country's electronics production. Despite concerted efforts by industry associations and the Government to increase production of components, this percentage has changed little in 24 years. Components that are manufactured tend to be on a relatively low level of technology—the vast bulk being picture tubes and other components for television and radio, printed-circuit boards, capacitors, resistors, and connectors. Active semiconductor devices, including ICs, account for only 10 percent of component manufacture, or less than 2 percent of the total electronics manufactured in India.

The primary reason for this imbalance is economic; manufacturers shun the components sector because of its high ratio of investment to revenues earned from production—close to 1:1, as compared to about 1:6 in the equipment sector. High capital costs and interest rates in India discourage investments in capital-intensive industries, like component manufacture, because the finished products cost too much to be competitive in world markets.

RISING TO THE CHALLENGE. Though it has its share of unique challenges, the Indian electronics industry is like those of more advanced countries in at least one way: a huge quantity of garden-variety electronics winds up in commercial and consumer products, but the most advanced applications are the almost exclusive province of Government establishments like defense. Interestingly, in electronics as in several other technologies, India has managed to respond to setbacks—the denial of technology by other countries or the exacting of extremely high prices for support and spare parts—by turning them into research or full-scale development opportunities.

Indeed, India's electronics industry itself was born out of experiences in the 1960s and 1970s, when the country was forced to pay exorbitantly for support services and spare parts for equipment that had been imported at reasonable cost. One category that received special attention in this regard was military technology, including radar, communications, and control and guidance systems. From the very beginning, the objectives were threefold: to provide cost-effective support to existing equipment, to upgrade technologies and capabilities, and to transfer appropriate military technologies to industrial and other civilian uses.

In the early 1970s, the major electronics industries were the Indian Telephone Industries, established in 1948 to serve the country's telephone and communications needs; Bharat Electronics, founded mainly to manufacture radar and military communications equipment; and the Electronics Corp. of India, which had been set up in 1966 to cater to the electronics and control-instrumentation requirements of the atomic program. All three have since diversified into many other product lines, and account for a sizable share of the Indian market [see middle table, this page].

In fact, their influence is still recognizable in one of India's most recent technical thrusts, into parallel computing. Separate, thriving efforts in this area are under way at the Centre for Development of Advanced Computing in Pune, the Bhabha Atomic Research Centre near Bombay, the Centre for Development of Telematics in New Delhi, the National Aerospace Laboratory at Bangalore, and the Advanced Numerical Research and Analysis Group in Hyderabad.

EXPANDED TASKS. Recognizing the need for a separate agency to take an overall view of end applications and to plan and promote technological and industrial development, the Government created the Department of Electronics. Unlike the telecommunications, defense, space, and atomic energy agencies, whose efforts were directed to meet in-house needs, the Department of Electronics was charged with ensuring that applicable technologies developed in these spheres benefited other sectors, especially aviation, railways, meteorology, telecommunications, and industrial applications.

As it grew, the department took on added responsibilities, such as establishing a national laboratory for work in microwave and millimeter-wave technologies, and programs in electromagnetic compatibility and reduction of electromagnetic interference. India has benefited in the latter area from support by the United Nations Development Programme and the UN's Industrial Development Organization. The micro- and millimeter-wave laboratory, called the Society for Applied Microwave Electronics Engineering & Research (Sameer), now earns about half of its operating revenues by providing technical consultancy services to Government and commercial clients. It is now set on expanding its horizons by offering its services to other countries, particularly in south and southwest Asia.

Along with the atomic energy and space agencies, the defense establishment in India has been one of the pillars of the electronics edifice. The Defense Research and Development Organization, where almost all defense electronics R&D is carried out, has about 48 laboratories working in fields ranging from weapons systems to agriculture and medicine. Ten of these laboratories have invested a lot of effort in electronics, into which over the last couple of decades they have poured roughly 10 billion rupees (about US $300 million at current exchange rates). In addition, the

Productivity in electronics manufacture

Country or region	1990 industrial production, US $ billions	1990 direct employment, millions
India	5 (a)	0.3
Japan	204	1.8
United States and Canada	218	2.4
Western Europe	166	(Not available)

(a) At 1990 conversion rate of 18 rupees to the U.S. dollar.

India's top 10 electronics companies

	1992 production, US $ millions
Indian Telephone Industries (a)	420
Bharat Electronics (a)	230
BPL	140
Pieco Electronics & Electricals	100
Videocon	90
Samtel (India)	70
Titan Watches	70
Electronics Corp. of India (a)	60
JCT Electronics	50
Wipro Info Tech	50

(a) Wholly or partly government-owned.

Revenues from electronics in India

	Revenues, rupee millions		
Electronics category	1971	1980	1990
Consumer	525	2140	29 380
Industrial	130	1600	14 000
Computers	—	—	8 200
Communication and broadcast equipment	395	1845	16 300
Strategic	280	680	5 700
Components	400	1630	15 200
Export zones	—	165	3 220
Total	1730	8060	92 000

Source of tables: Department of Electronics, Government of India

Department of Electronics

A phased-array radar for studies of the atmosphere was built by India's Society for Applied Microwave Electronics Engineering & Re-search. The $2.5 million radar has 1024 crossed-Yagi antennas, and is one of only perhaps half a dozen such systems in the world.

defense industries and the Department of Electronics (under its National Radar Council technology program) have invested about 1500 million rupess—about $50 million—in R&D of defense-related electronics.

NOTABLE ADVANCES. Though comparatively small, these investments have produced several noteworthy achievements in radar, sonar, communications, surveillance and night-vision systems, and components. In radar, for example, a phased-array system that can provide surveillance, multiple target tracking, and weapon guidance—while stationary or on the move—has been built. For air-defense roles it has command, control, and communications features for both autonomous and hierarchical operation.

The system's array of more than 4000 ferrite phase-controlled antennas was designed and built completely within India. The beam the antennas produce is electronically stabilized in space to compensate for the pitch and roll of the radar's platform, and it is steered by a special-purpose, high-speed computer.

Another phased-array radar has been built for studying the mesosphere, stratosphere, and troposphere; it is one of only four other such radars in the world. India's system has 1024 crossed-Yagi antennas, capable of producing a peak power aperture product of 30 GW-m^2 [see photo above]. Six beam directions are available in a computer-controlled mode, and the radar uses 16- and 32-bit complementary codes that, ideally, produce no side lobes. The radar was built for a mere $25 million by Sameer, and is operated by an inter-university center for upper atmosphere research.

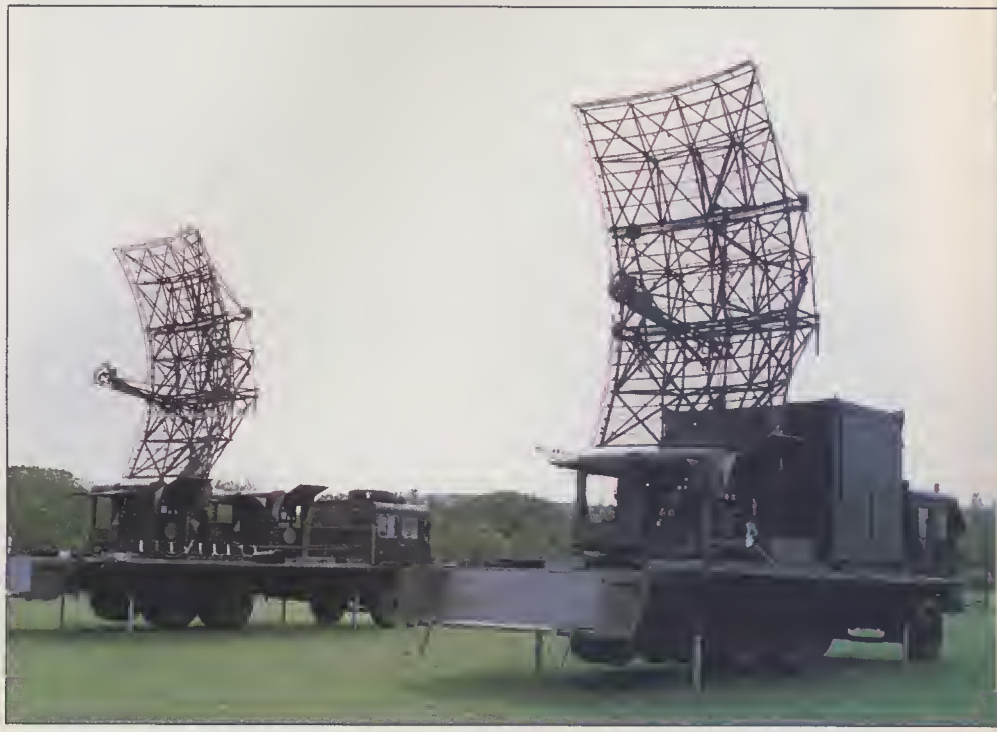
Designing and building these and other systems has helped India to establish a strong base of knowledge and expertise in radar. In fact, more than half a dozen industrial houses are now equipped to take on the design, manufacture, and installation of radars. Simultaneously, industrial growth has bolstered the capabilities of both Government-owned and private companies in communications, information systems, and in-strumentation. Several organizations have received quality certification under ISO 9000, and are equipped to build, install, and maintain complex radars and communication systems within India and abroad.

COUNTERING THE THREAT. As any military planner knows, radar is necessary but hardly sufficient on the modern battlefield. As was demonstrated yet again in the Persian Gulf, electronic countermeasures and even counter-countermeasures are the norm in war. However, equipment based on advanced technologies in these vital areas is often protected by those countries that have it, and is therefore not readily available in international markets.

A specialized industry now exists in India to manufacture electronic warfare systems that are based on design and development work with sensitive and cutting-edge technologies. Currently in production is a computer-controlled, integrated countermeasure and counter-countermeasure system. Operated by just one individual, it can intercept signals over a multi-octave spectrum, identify and classify them, and immediately initiate countermeasures against the threat radar.

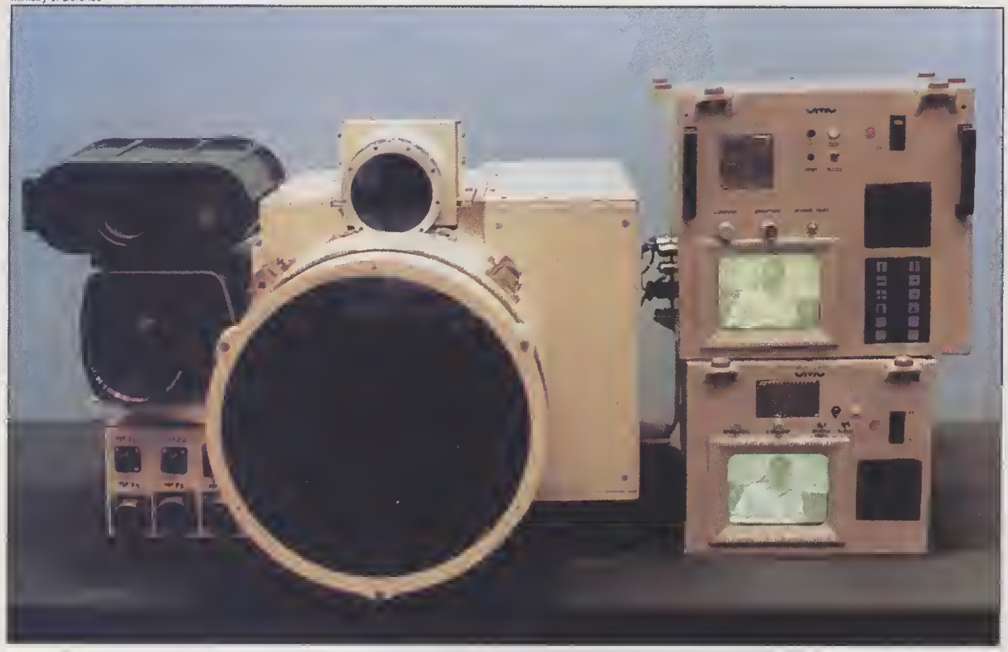
A companion system employs separate high–intercept-probability receivers for measurement of frequency, using instantaneous techniques in octave bands. It also measures bearing; to this end it uses the amplitude-comparison monopulse technique

Ministry of Defence



This transportable digital communications gear incorporates state-of-the-art, low-noise microwave synthesizers and gallium arsenide amplifiers, providing channels for speech, teleprinters, and computer data and processing. The truck-mounted systems are fully self-contained, and can be deployed and brought on-line in less than an hour. The segmented antennas can be folded rapidly and secured for transport and redeployment.

Ministry of Defence



A thermal imaging system with a high-resolution camera based on charge-coupled devices has found uses in the military, law enforcement, and industrial security. It has mercury-cadmium-telluride sensors integrated with low-noise amplifiers and real-time image processors.

with an array of eight spatially displaced antennas. An exhaustive radar library, divided into priority and nonpriority sections, may be preprogrammed with intelligence information on emissions likely to be encountered in a particular mission.

SONAR SPINOFF. Another detection technology, with perhaps the greatest spin-off potential for India, is sonar. With its vast coastline and prodigious need for food, fisheries are a critical component of India's development. Yet most Indian fishermen are still using grossly inadequate equipment that has changed little in centuries. Recently, though, a sonar system for locating shoals of fish was spun off from a military system.

The original system, now used in the Indian Navy, is an active-passive one with both hull-mounted and variable-depth arrays. It uses a microprocessor-based reconfigurable signal and an intelligent display, and can track more than one target. Features include multimode transmissions and classification using doppler and pattern-recognition techniques.

As with radar systems, the design and construction of these sonars have bred a knowledge base and infrastructure to build related and more sophisticated equipment, including transducers and displays.

Secure, reliable communications is another military need that has been addressed. Digital gear that can be operated in troposcatter or diffraction mode provides high-quality, multichannel communications for military, tactical, or remote-area uses. The equipment and its associated radio frequency and multiplexing gear are fully self-contained and can be mounted on a vehicle.

The system is differentially encoded, and based on quadrature phase-shift keying with coherent detection. The radio incorporates gallium arsenide field-effect transistors, a low-noise microwave synthesizer, and a microcircuit-based predetection combiner. The multiplexing system has a capacity of 24 speech channels, thirty-two 100-baud teleprinter channels, four computer data channels of 2400 bits per second, and four 100-baud computer supervisory channels. With its collapsible antenna, the entire system can be up and running in under an hour.

Night vision devices are also proving versatile. These include passive and active varieties, based on advanced image intensification and infrared technologies developed in India. Although this kind of equipment is obviously defense-driven, it is finding many applications in law enforcement and industrial security. One recent system is a high-resolution, charge-coupled–device camera and thermal-imaging system for the passive detection and recognition of targets at night or in bad weather [see photo above]. The equipment uses mercury-cadmium-telluride sensor element's integrated with low-noise amplifiers and real-time image processing. A NdYAG laser range-finder enables precise range estimation of the detected object.

BACK TO BASICS. Systems of this nature are a testament to what can be achieved in the face of dire deficiencies in component production. Even so, for the sake of security and self-reliance, and to exploit the country's tremendous design potential, India will have to improve its techniques and technologies for producing components and devices. As a national strategy, the Government is now emphasizing such development.

At present India has two IC wafer fabrication facilities (both in Bangalore). A third, 1.2-micrometer CMOS facility at the Semiconductor Complex Ltd. near Chandigarh is slated to go on stream by the end of this year. Following the lead of Texas Instruments, very large-scale IC design and related software-development units have been set up by SGS Thomson, Cadence Design Systems, and SAS.

India's Department of Electronics has also taken initiatives in VLSI design by launching R&D projects in academia, government, and industry. Also, a United Nations–assisted Centre for VLSI design and prototyping is being set up within the department itself.

A number of application-specific ICs have been designed in India and fabricated abroad. These include a Graphics and Intelligence based Script Technology chip and a submicrometer numerical coprocessor. In addition, a Gallium Arsenide Enabling Technology Centre is going up in Hyderabad.

So far, some micro- and millimeter-wave components have been fabricated, some of them based on surface–acoustic-wave devices, including filters, delay lines, convolvers, and pulse-compression network,. These parts are needed not only in military radars and electronic warfare systems, but also in cost-effective communication equipment, identification tags and other industrial security gadgets, and consumer products.

Clearly, advanced technology industries managed to translate India's low-wage structure into commercial advantages for supplying radars, specialized communications gear, and similar equipment at costs that were far below international price levels. These industries could now participate as equal partners with their counterparts in developed nations to serve global markets, combining India's technological talents and low-wage structure with the manufacturing and commercial strengths of the developed-world partners.

In today's global rush for new electronics and information technology, a nation can measure its wealth by the number of people it has working at the cutting edge of technology. Without these riches, the meager $350 million India has spent on advanced electronics technologies during the last two decades could not have produced as many tangible results as it has. India's challenge for the future will be translating this technical success into industrial momentum.

V. Prasad Kodali (F) is adviser, Department of Electronics, an agency of the Government of India. He previously worked at the Tata Institute of Fundamental Research in Bombay. He received the IEEE Centennial Medal in 1984 and of a Vasvik Research Award, a national recognition for Electronic Sciences and Technology, in 1989.

Vasudev K. Aatre (SM) is chief controller of research and development in the Indian Ministry of Defense. He was formerly director of the Naval Physical and Oceanographic Laboratory at Cochin, India, before which he had worked in Canada.

Electric power: a Government priority

As in so many aspects of its culture and development, electrification in India is a study in contrasts. On the one hand, in a scant 43 years, generation capacity has grown from 2300 megawatts to about 70 000 MW. The country's transmission system includes a 250-MW back-to-back direct-current link and a 900-km, 1000-MW dc line. An experimental 200-km, 100-MW dc line built almost entirely with indigenously developed and built technologies—right down to the thyristors in the converter stations—is in operation. There are hundreds of kilometers of 400-kV lines, as well as a newly built laboratory, in Hyderabad, for testing transmission systems and equipment at up to 1000 kV.

On the other hand, annual per-capita energy use in India is roughly 300 kWh, or well under half of what it is in Iran. Furthermore, the reliability of the bulk power supply is very poor and its quality is alarmingly below the standards of the developed world. Plant availability figures, an indication of how well plants are run, are low. The average generating plant load factor (the ratio of a plant's average output to its rated maximum capacity) is about 57 percent. For comparison, load factors in developed countries are normally higher than 70 percent. Low-frequency operation is routine throughout India and harms generating units and loads alike.

In addition, more than two decades after regional power grids were formed, there is still no adequate tariff structure for power interchanges between Indian states. Interconnected operation is therefore usually blocked, leaving each state system to operate in isolation. Crisis management has become the order of the day, and load shedding—both scheduled and unscheduled—has become common. Customers have gotten used to periodic brownouts and blackouts.

Keenly aware of this serious obstruction to future development, the Government of India has made generating capacity and transmission-system additions a priority in its five-year economic plans. The current plan, for the period 1992–97, originally envisioned an addition of 38 000 MW, or about 50 percent of India's installed capacity. This would raise peak power availability to just over 65 000 MW, to meet anticipated peak demand of nearly 70 000 MW. Expected energy availability would be 472.7 terawatthours, for a requirement of 395.3 TWh. The plan also called for transmission-circuit additions of 4000 km of 400-kV line, 1200 km of 800-kV line, and 1500 km of high-voltage dc (HVDC) line. The nationwide totals in these three categories would then be 32 000 km, 3000 km, and 2000 km, respectively.

Regrettably, all of these figures have proved too ambitious in light of significant financial constraints. The hoped-for generation additions, for example, have been reduced from 38 000 to 22 000 MW, and more realistic expectations for the other numbers would be around 60 percent at most of the targeted figures. Consequently, in 1997, at the end of the planning period, the country would fall short by about 15 percent in meeting both energy and peak-demand requirements.

SHIFTING THE MIX. At present, India derives about 67 percent of its electricity from coal, 8 percent from oil, 23 percent from hydroelectricity, and about 2 percent from nuclear power. In coming years, however, this mix is likely to shift, with nuclear and renewable energy sources accounting for more of the mix and fossil fuels for less. By the end of the 10th Economic Plan in 2007, nuclear power is expected to expand to 10 000 MW, or roughly 8 percent of the total generation mix.

By this time, the Government's support of R&D of a number of renewable sources is also expected to begin paying off, with plants coming on-line based on technologies like micro-hydroelectric, geothermal, solar, wind, and biomass. All these will have the advantages of short gestation periods, reduced transmission requirements, and inexhaustibility. Studies have indicated that India's average level of solar insolation is 800 watts per square meter, a total wind potential of about 20 GW, and roughly 2 GW of mini- and micro-hydroelectric potential. All told, the 8th Plan calls for addition of some 2 GW of renewable capacity.

Capacity additions are of course pointless without commensurate expansion of transmission systems. Unfortunately, this idea has not always guided electrification in India, and growth in transmission systems of late has not kept pace with additions to capacity. Underlying this mismatch are several causes, including right-of-way clearance difficulties and very long waiting periods associated with the building of transmission lines, which are often more onerous than securing the environmental clearances for a large baseload thermal power station.

Along with growth in generation and transmission capacities has come greater complexity and the need for closely interconnected and integrated operations. At present, India is divided into five independent grids, each with a Regional Electricity Board to coordinate load dispatch operations within the grid. However, the facilities available to these boards are far from adequate for controlling the interconnected operation of a

With the completion of several new facilities over the last couple of years, India can now test all of its own high-power electrical equipment, a rarity among developing nations. At the Central Power Research Institute's High Power Laboratory in Bangalore, tests can be performed up to 2500 megavoltamperes.

Glenn Zorpette

M. Ramamoorty Central Power Research Institute

complex power system. At a minimum, modern, computer-based data acquisition systems and effective, reliable communications would be needed before the five grids could be combined into a national system.

Meanwhile, transmission voltages are increasing. At its Hyderabad laboratory, the Central Power Research Institute, under the Government's Ministry of Power, is stepping up its work on extra- and ultra-high-voltage transmission systems. In recent years, it has constructed a simulation center for power systems, a high-power switchgear testing laboratory, and a 1-km-long experimental transmission line that can be energized up to 1000 kV.

The engineering expertise for designing such advanced systems and the trained workforce to operate them are both on hand in India. Nonetheless, serious problems are often encountered in maintaining the stability of the conventional power systems that are already in place. Peak demands on power have always exceeded the available capacity, and the gap yawns wider every year. Furthermore, transmission and distribution systems are grossly lacking in reactive compensation. Line losses are also a problem—transmission and distribution losses average about 21 percent of all power generated. To address the problem, the government recently established a Power Grid Corp. to look after rural networks.

Not all problems are technical, moreover. To promote rural electrification and agriculture, power is provided to farmers at an average of only 13 percent of actual cost. On top of this, power losses due to pilferage exacerbate an already acute shortage of financial resources. Other problems contributing to far-from-satisfactory performance of electric utilities include an antiquated, unremunerative tariff structure and inadequacies in automated controls.

Such straits are forcing reexamination our strategies in power development. Besides reducing transmission and distribution losses, improving plant load factors, and implementing strictly disciplined intra- and inter-regional power transfers, we must seriously consider an extensive program of energy conservation. Even marginal attempts at conservation could result in savings of at least 10 percent, recent studies have shown.

NO INCENTIVE. For example, nearly a quarter of India's electricity is used by some 9.4 million irrigation pumps that are notoriously inefficient and decrepit. When the Indian Rural Electrification Corp. replaced 23 000 of these old pumps with better ones in the mid-1980s, the electricity used by them fell 25 percent, enough to pay for the retrofits in less than two years. However, with electricity prices so low, India's farmers have little incentive to make such improvements.

Attention also needs to be paid to new and emerging technologies in transmission, distribution, and utilization. The Indian government is supporting several field-oriented R&D projects to assess the performance of various Indian-developed technologies and implement them if they prove satisfactory. These include variable-degree series compensation, static volt-ampere–reactive systems, and HVDC transmission, all of which will enable better utilization of transmission corridors and better performance of interconnected networks.

The relative shortage of peaking power, in comparison with electric energy supply, points to a need for more pumped-hydro storage, gas-fired combustion units, and stronger reactive-compensation components of both transmission lines and loads. Priority should be given to the construction of strong inter-regional tie lines between the northeastern region, where there is a surplus, and the east, and also between the east and southern regions. Another priority should be the building of modern load-dispatch and effective communication facilities. Appropriate exchanges of power between the western and southern regions through existing and new interconnections should also be considered.

Direct-current, back-to-back ties could help. So could various load-management techniques becoming common in developed countries, such as rostering and staggering, demand-side management, and incentives for using more electricity off peak. But what might be most effective is a reevaluation of the responsibilities and relationship of the State Electricity Boards with the Regional Electricity Boards, which oversee electricity transfers within the regional grids.

One of the paramount rules in interconnected operations is grid discipline with regard to voltage and frequency; but in the face of shortages and increasing demand, this discipline has been hard to maintain. Some state boards take unfair advantage of the interconnection, rather than behaving in a cooperative manner. Overdrawing of energy, especially during times of peak demand, has become common. For lack of statutory power, the regional boards cannot enforce discipline. The problem has become so severe that, in order to keep their systems in operation, some of the state boards frequently have to turn to *ad-hoc* measures on almost an hour-by-hour basis.

Hopefully, the day is not too far off when a more equitable tariff structure and interchange rules combine with improved reactive compensation and other technical enhancements to establish and improve safety margins. India is fortunate to have the technical and managerial expertise needed to put these measures into effect and improve system operation. With a modest increase in resources, a new emphasis on conservation, and a thorough regulatory overhaul, India could bring new life to its efforts to electrify and make life better in the world's second largest country.

M. Ramamoorty (F) is director general of the Central Power Research Institute, under the Indian government's Ministry of Power. He was previously a professor of electrical engineering at the Indian Institute of Technology in Kanpur and chief of research and development at M/S Hindustan Brown Boveri Ltd. in Baroda. He has received many awards and recognitions, and was recently named the IEEE's Distinguished Lecturer for Region 10.

Losses incurred by state electricity boards

Reason for loss	Amount, rupee billions	Percent
Low agricultural tariff	33.2	65
Other low tariffs	8.2	16
High transmission and distribution losses	4.7	9
Overstaffing	4.1	8
High coal consumption	2.8	5
High auxiliary consumption	0.9	2
High fuel oil consumption	0.7	1
Low plant load factor	0.6	1
Low operations and maintenance provisions	–4.1	–8
Total	51.0	100

Numbers and percentages are rounded off.

Source: *NCPU Journal*, January 1992

To probe further

GENERAL. Excellent surveys of the Indian business, political, and technological situations appear from time to time in *The Economist* and the *Financial Times* of London. Published in its May 4, 1991, issue, *The Economist*'s "Survey of India" remains one of the best recent summaries of the Indian predicament. Information on reprints can be obtained by telephoning 212-541-5730 in New York City (fax: 212-541-9378; 071-839-2968 in London). The addresses are : The Economist Newspaper Group Inc., 111 West 57th St., New York, NY 10019; 25 St. James St., London SW1A 1HG, England. The magazine also has an "intelligence unit," which issues political and economic forecasts in conjunction with Business International Ltd. Write to: The Economist Intelligence Unit, 40 Duke St., London W1A 1DW, England.

The *Financial Times* also does periodic surveys of India; the most recent were pub-

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The tenants of India's "Electronics City," south of Bangalore, are a "who's who" of international high technology. The area has dedicated communications links to other global technology centers, computer facilities, and other technical infrastructures, many of which were set up by the Government as part of an effort to jump-start high-technology industry in India.

lished with the Sept. 30, 1993, and June 26, 1992, issues of the newspaper. A survey of the West Bengal area of India was published last Jan. 11. More information can be had by telephoning 071-873-3324 or 071-873-3213. The *Financial Times* also has a bimonthly "India Business Intelligence" newsletter. Contact the Marketing Department, Financial Times Newsletters, 126 Jermyn St., London SW1Y 4UJ, UK; 071-411-4414.

Nature devoted most of its Dec. 16, 1993, issue to a report on "Science in India." For a copy, contact *Nature*, 65 Bleecker St., New York, NY 10019; 212-477-9600; or Macmillan Magazines Ltd., Brunel Road, Basingstoke, Hants., UK RG 212X5.

The IEEE India Council publishes a magazine titled *Horizons*. Its address is E-2 Greater Kailash-II, New Delhi, 110 048. The Institution of Engineers (India) also has a journal and supplementary bulletin; they are issued from the institution's offices at 8 Gokhale Rd., Calcutta, 700 020.

A report on "Publishing and Copyright in India" was published by Rights: Copyright and Related Rights in the Service of Creativity, published quarterly by the International Publishers Association and the International Group of Scientific, Technical, and Medical Publishers. Write to IPA Secretariat, Ave. de Miremont 3, CH-1206 Geneva, Switzerland.

Most of the development statistics quoted in the beginning of the overview article were taken from the *World Development Report 1993*, published for the World Bank by Oxford University Press (the 1994 report is expected out in June or July). The World Bank has headquarters at 1818 H St., N.W., Washington, DC 20433; 202-473-1782.

SOFTWARE. Edward Yourdon's *Decline & Fall of the American Programmer* has a 33-page appendix on "Software Technology in India." The book was published by Prentice Hall in Englewood Cliffs, N.J., in 1992. Yourdon's magazine, *American Programmer*, published a special report and a seven-page article on the Indian software industry in its October 1989 and March 1993 issues, respectively. Back issues are US $45, and can be obtained by calling 617-648-8702, or writing to Cutter Information Corp., 37 Broadway, Arlington, MA, 02174-5539.

"The Software Industry in India (1993–94) Strategic Review," edited by Dewang Mehta, was published by the National Association of Software Service Companies in New Delhi.

NUCLEAR TECHNOLOGY. *Nuclear News* produced a special issue on "India's growing nuclear energy program" in April 1990. The publication's offices are at 555 N. Kensington Ave., LaGrange Park, IL 60525; telephone, 708-352-6611.

"India and Pakistan's Nuclear Arms Race: Out of the Closet, But Not in the Street," by David Albright of the Institute for Science and International Securit,y appeared in the June 1993 issue of *Arms Control Today*, which is published by the Arms Control Association, 11 DuPont Circle, N.W., Washington, DC 20077.

The World Inventory of Plutonium and Highly Enriched Uranium, 1992, published by Oxford University Press and the Stockholm International Peace Research Institute, devotes part of a chapter to India's program. It was written by Albright, Frans Berkhout, and William Walker. Oxford University Press has an office at 200 Madison Ave., New York, NY 10016; phone, 212-679-7300.

AEROSPACE TECHNOLOGY. *IEEE Aerospace and Electronic Systems Magazine* devoted its February 1993 issue to the Indian space program. Back issues are available ($10 for members, $20 for nonmembers, plus $4 postage and handling) from the IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-981-0060.

Annual reports are published each year by the Indian government's Department of Space, which is headquartered on Airport Road, Vimanapura Post, Bangalore 560 017.

TELECOMMUNICATIONS. The Indian government's Department of Telecommunications publishes annual reports; the department is based at Sanchar Bhavan, 20 Ashoka Rd., New Delhi, 110 001.

ELECTRONICS AND DEFENSE. Michael Pecht, director of the Electronic Packaging Research Center at the University of Maryland, has produced a report on electronics packaging technologies in India, Taiwan, and Malaysia. Write to Pecht at Calce Center, University of Maryland, College Park, MD 20742.

The Indian government's Department of Electronics also puts out an annual report. Its headquarters are in the Electronics Niketan, CGO Complex, New Delhi, 110 003.

POWER AND ENERGY. Bharat Heavy Electricals Ltd. publishes a quarterly journal and a monthly newsletter. Contact the Editor, *BHEL Journal*, Bharat Heavy Electricals Ltd., BHEL House, Siri Fort, New Delhi, 110 049. ◆

Managing signal integrity

Today's high-speed printed-circuit boards and multichip modules require integrated design systems that include signal integrity analysis tools

Year after year, the clocks that govern IC speeds become steadily faster. In computer systems, clocks that now stand at 100 MHz will rise to 1 GHz later in this decade. Digital Equipment is developing a 1–2-GHz version of the Alpha AXP chip; Intel promises faster Pentiums; and Fujitsu has a 1-GHz Sparc processor in the works for 1996. Digital communication systems are getting faster as well, for data rates of 2 gigabytes per second or more are now common in personal computer networks, local- and wide-area networks, and cellular and optical-fiber systems.

But when chips run at such high frequencies and signal edges consist of frequency components that are still higher, the interconnects that link them on circuit boards and modules start behaving like transmission lines. A new set of analysis tools is therefore needed to take the high-speed effects into account [Table 1].

DEFINING HIGH SPEED. A simple driver-receiver circuit illustrates the problem [Fig. 1]. So long as the interconnects are short and the clock rates are low, receivers are loads for the driver and can affect its output waveform. In cases of this kind, long-familiar techniques, such as Ohm's law and Kirchhoff's laws, serve to determine the waveforms. Loading due to interconnects is counted in as lumped capacitance to ground or as RC tree networks.

Things change once the line becomes long enough for the signal's rise and fall times to roughly match its propagation time through the interconnect. Then the interconnect electrically isolates the driver from the receivers, which no longer function directly as loads to the driver. Instead, within the time of the signal's transition between its high and low voltage levels, the impedance of the interconnect becomes the load for the driver and also the input impedance to the receivers. Such transmission line effects as reflections, overshoot, undershoot, and crosstalk distort the signal [Fig. 1], and the system may no longer be analyzed with the same circuit theory as is used for slower devices.

Ravender Goyal Mentor Graphics Corp.

Nor is clock rate the sole basis for characterizing a system as high-speed. For example, in a circuit with a 1-MHz clock whose rise time is 1 ns, transmission line effects occur during signal transitions because of their fast slew rate. Since the clock rate is low, the signal will eventually attain steady state. But its fast rise time generates reflections and ringing; and the resulting signal may cross the threshold voltage several times, falsely triggering circuits. The primary factors that determine whether high-speed signal distortion effects should be considered are interconnect length, signal slew rate, and clock speed. Logic levels, dielectric material, and conductor resistance are among the secondary determinants.

A trapezoidal signal with finite rise and fall time has significant frequency components up to several times the clock rate. The fundamental frequency is that of the clock itself. The magnitudes of the higher-frequency components decrease at the rate of 20 dB per decade up to the frequency that corresponds to the rise time. For example, in the case of a 5-V, 100-MHz clock with a 50 percent duty cycle and a 1-ns rise time, the fundamental frequency has an amplitude of approximately 3 V, while the 1-GHz component has an amplitude of 0.3 V. Depending on ground definition and the occurrence of simultaneous switching, such large harmonics could have an unwelcome effect on circuit operation. This is of particular concern in a mixed-voltage design where some devices might have threshold voltage noise margins below 0.3 V.

Details of this nature determine how high in frequency the analysis of a high-speed design needs to go. As a rule of thumb, high-speed design techniques including signal integrity analysis should be adopted when the propagation delay in the interconnect is 20–25 percent of the signal rise and fall time.

Moreover, the overall clock cycle time is divided among signal validation, setup, and clock skew, as well as interconnect delay. Thus at 66 MHz, the present clock rate of the Pentium processor, the delay available for signal propagation is measured in the subnanosecond range, as Don Telian, manager of the Integrated Microcomputer Division at Intel Corp., Folsom, Calif., has observed. For success in designing a system using so high a clock rate, the engineer needs to estimate the interconnect delays with great accuracy.

FROM BOARDS TO MODULES. The design of printed-circuit boards that will operate at these high clock rates needs to factor in the electrical contribution of interconnects, which begin to behave as distributed transmission lines and coupled lines at clock rates above 30 MHz.

That this happens has been known in supercomputer designs for some time. The designers of high-performance systems had to do a lot of prototyping to study the problem before designing boards for high clock rates. Early on, the design tools available for addressing such issues were very specialized and meant to be used by the experts in the field. Companies like Cray Research, IBM, Sperry, Control Data, and Honeywell were pioneers in this area. They were forced to treat interconnects as transmission lines from the start of the design, according to Greg Doyle, vice president of engineering at Integrity Engineering Inc., St. Paul, Minn. Generally, they had a group of circuit gurus who understood the circuits and their electromagnetic properties in depth.

But now that the clock rates of today's personal computer boards and consumer systems are lending interconnects a disproportionate influence over board performance, Doyle believes that there is a need for signal integrity analysis tools intended for nonexperts to use.

Along with the rise in clock rates goes a rise in the complexity of custom and application-specific ICs, and also in the unsuit-

Defining terms

Coplanar waveguide: a transmission-line geometry in which a conductor pattern is located in the gap between two ground patterns—all in one plane on a substrate surface.

Microstrip: a transmission-line geometry with a single conductor trace on one side of a dielectric substrate and a groundplane on the other side.

Quasi-transverse electromagnetic mode: one in which the magnitudes of electric and magnetic fields in the directions other than perpendicular to the direction of propagation are small relative to the perpendicular components.

Stripline: a transmission-line geometry in which a single circuit trace is located in the dielectric material between two parallel ground planes.

Transverse electromagnetic mode: one in which both the electric and magnetic fields are everywhere perpendicular to the direction of propagation.

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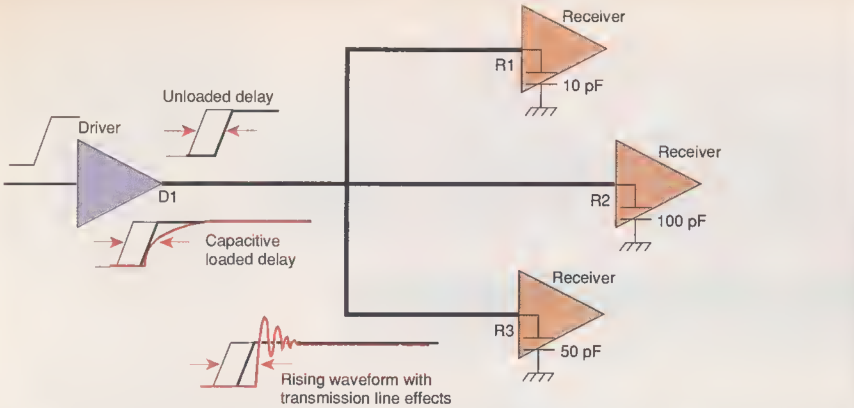


[1] When a clock pulse is applied to the input of a driver, it is delayed but maintains its waveform if loading is minimal. At low speeds, receiver and interconnect loading can distort the waveform. At high speeds, when transmission-line effects become important, ringing may appear.

ability of the one-chip-per-package approach. Pin counts often number several hundreds. Inter-chip and packaging delay can significantly boost the overall system delay if conventional printed-circuit boards are used. The engineer has to move on to increasingly efficient packaging technologies, such as multichip modules (MCMs).

These days, the MCM is emerging as one of the most important packaging technologies since the surface-mount device. Its advantages stem primarily from the elimination of the chip package with its associated parasitics. Because the MCM simplifies the component, it also improves the yield and shrinks the footprint.

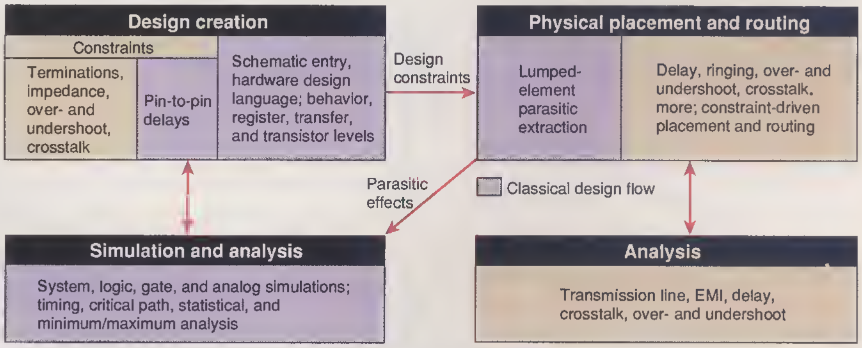
In all likelihood, MCMs will catch on in all electronic systems. Manufacturers are using the technology to aid communication among chips in mainframe computers and in telecommunication and optical communication applications. Tohru Handa, executive manager for the New Business Development Group at OKI Electric Industry Co. in Japan, said that his company has developed high-speed switching modules for local-area networks and asynchronous transfer mode telecommunications using MCM technology. Its next-generation 2.4-Gb/s switch modules and 150-Mb/s to 2.4-Gb/s optical interface module will also use MCMs.

HIGH-SPEED EFFECTS. When the wavelength of the signal of interest becomes short enough to roughly match the length of the interconnect, the distributed parameters of the transmission line cannot be represented accurately by means of a lumped-parameter equivalent circuit. At high frequencies, inductances and capacitances of short lengths of conductors cannot be neglected. These inductances and capacitances are distributed along the length of conductor and engender a signal that is distorted by reflections, ringing, and crosstalk. Ground bounce, narrow lines, inaccurate semiconductor models, and physical and electrical characteristics are other areas that need watching.

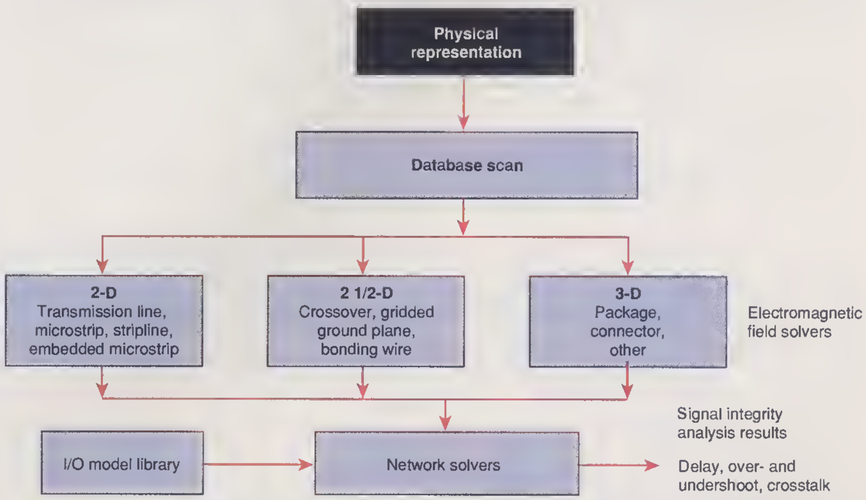
The most common geometries used in the design of printed-circuit boards and MCMs are microstrip and embedded microstrip lines, strip lines, and coplanar waveguide structures. Their physical properties include the width, spacing, and thickness of the lines and the thickness of the dielectric material; important electrical parameters are metal-line resistivity and skin depth, dielectric constant, and dielectric loss factor.

Lack of a good ground is a key problem often encountered in high-speed designs. Inductance frequently exists between the virtual and actual ground due to interconnects and lead inductance, for example. If many drivers switch simultaneously, a voltage proportional to the rate of change of current with time is induced across the interconnect, which may cause false switching of devices on the victim line. Vias, bond wires, and package and connector pins also contribute to the effect, which is known as ground bounce or delta I noise. In MCMs, moreover, the meshed ground plane adds to the adverse effects. [See "Diagnosing high-speed effects," p. 58.]

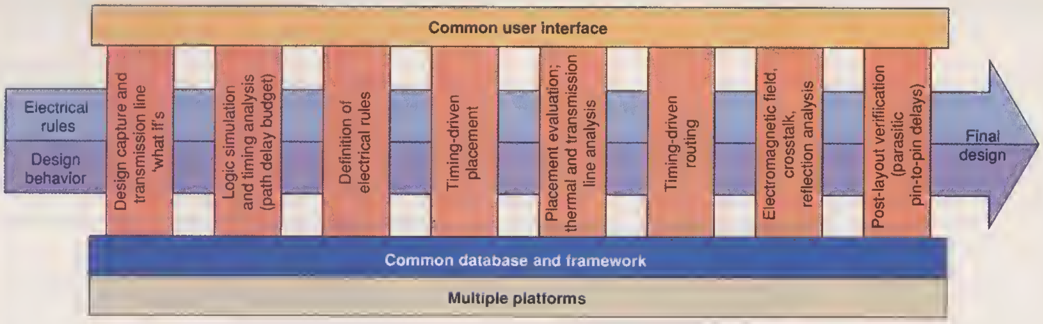
In fact, there are a number of issues of particular interest to designers of MCMs for high-speed applications, according to Larry Rubin, president of Quad Design Technology Inc., Camarillo, Calif. While the short run lengths in MCMs tend to reduce interconnect delay and other length-dependent transmission line effects, the narrowness of the lines tends to engender significant losses due to resistance and the skin effect, so that signals at higher frequencies and edge rates are degraded. Further, because of higher wiring density and the unusual via structures, the effects of crossover and via parasitics can be stronger in MCM designs than in traditional printed-circuit board approaches. Finally, ground plane effects (both ac and dc) need to be accounted for carefully in this context, since severe ground bounce and an



[2] An increase in signal edge speed is accompanied by a change in design methodology from the classical design approach that considers pin-to-pin delays and lumped parasitic parameters to a high-speed analysis based on the electromagnetic properties of the physical structures.



[3] Signal integrity analysis of printed-circuit boards and MCMs includes electrical representations of such physical structures as interconnects, ground and power planes, packages, and connectors. Modeling tools develop mathematical representations of drivers, receivers, loads, and terminations; then, network solvers analyze the overall electrical system, yielding output waveforms.



[4] A concurrent design system is critical for reducing the design cycle time and the number of iterations. Such a system includes design entry software, analysis and synthesis tools, reliability analysis, and an interface to documentation and manufacturing systems.

effective shift in threshold voltage can result from the combination of high current densities with the thinner (and sometimes noncopper) metallizations for power distribution.

The speeds, noise margins, logic swings, and other electrical properties of the logic families used (CMOS or TTL, for example) determine the critical interconnect length beyond which high-speed effects are a concern [Table 2]. Intel's Telian has pointed out that driver and receiver models likewise influence the simulation of the overall characteristics of signal propagation and distortion. The accuracy of signal integrity analysis depends on the accuracy of the semiconductor circuit models, whose availability is crucial to IC suppliers, IC users, and vendors of electronic design automation equipment. IBIS—the input/output buffer information specification—is an open forum that is developing a generic standard capable of offering accurate circuit models, while maintaining the confidentiality owed to proprietary information.

HIGH-SPEED DESIGN. Designers are by now familiar with the classical approach to board design, which is appropriate only when the interconnect parasitics can be approximated as lumped elements [Fig. 2]. To review the steps briefly, a conceptual design is followed by analysis of logic, timing, and critical path, and analog and other simulations are performed to determine the logical and timing accuracy of the design. Then the logical design is converted into a physical design by means of physical layout tools. Physical analysis tools are used to extract lumped parasitic elements to account for interconnect loading. These lumped parasitics are back-annotated to the simulators to verify the validity of the design after physical layout.

For high-speed designs, however, detailed interconnect and signal integrity analysis are required in addition [Fig. 3]. Central to signal integrity analysis are the electromagnetic (EM) field solver (or Maxwell's equations solver), models of drivers and receivers, the electrical network solver, and the electromagnetic interference (EMI) analyzer.

In this process, the layout database is scanned for unique interconnect and coupling structures and discontinuities. Then, EM field solvers use the layout information to solve Maxwell's equations by numerical methods. Input to the solvers contains such physical data about the printed circuit or multichip module as the layer stack-up, dielectrics and their thicknesses, placement of power and ground layers, and interconnect metal, width, and spacing. The output is the mathematical representation of the electrical equivalent circuit of physical structures on the board or module.

Some field solvers analyze a structure in two dimensions on the assumption that the

1. Tools for signal integrity analysis

	Ansoft, Pittsburgh	Cadence Design Systems, San Jose, Calif.	Contec Microelectronics USA, San Jose, Calif.	High Design Technology, Turin, Italy (a)
Product	Maxwell—3D	DF/Sig/Ansoft	ContecSI—ContecPlane	Presto
Year released	1987, 1993	1993	1991, 1993	1992
Nature of tool				
Field solver: 2-, 2½-, 3-D	2-, 3-D	2½-, 3-D	2½-D	2-D
Network analysis: Spice, non-Spice	—	Non-Spice	Spice	Non-Sp
Driver/receiver modeling	—	Yes	—	Yes
Other	Solid modeling	Schematic capture, layout	Analog, mixed-signal simulator	—
Application				
Transmission line analysis				
Lossless/lossy	Yes/yes	Yes/yes	Yes/yes	Yes/yes
Traces on gridded/without ground plane	Yes/yes	Yes/yes	Yes/yes	Yes/yes
Crosstalk analysis				
Lossless /lossy model	Yes/yes	Yes/yes	Yes/yes	Yes/yes
Coupled lines on gridded/not on ground plane	Yes/yes	Yes/yes	Yes/yes	Yes/yes
Power/ground plane analysis	Yes	Yes	Yes	Yes
Interface to Spice	Yes	Yes	Yes	Yes
Package analysis	Yes	Yes	—	Yes
Connector analysis	Yes	Yes	—	Yes
Platforms supported (d)	1–4	1, 2	1, 2, 7	1, 2, 5
Printed-circuit board/multichip module layout/router software interfaces				
Mentor Graphics' Board Station	—	—	Yes	Yes
Cadence Design Systems' Allegro	Yes	Yes	Yes	Yes
Cooper & Chyan Technology	—	—	—	—
Intergraph	—	—	—	—
SciCards	—	—	—	—
Viewlogic	—	—	—	—
Racal-Redac	—	—	Yes	Yes
Other interfaces and formats	—	—	—	—

(a) Modeling and applications based on measurements only.
(b) Model library for use in signal integrity analysis. No analysis.
(c) Also Monte Carlo, high-speed calculator and high-speed electrical rules.

third dimension is symmetrical; they can be used for regular transmission lines and coupled lines on boards or modules. Others solve Maxwell's equations in 2 1/2 dimensions, and are required for more complex structures such as bends in interconnects, gridded ground and power planes, and packaging discontinuities. More accurate tools that solve Maxwell's equations in all three dimensions can handle connectors, vias, packages, and other complex structures. In choosing among the varieties of field solvers, the complexity of the structure must be considered, and the accuracy of the computation must be weighed against the performance and computational cost.

Secondly, electrical models representing drivers, receivers, load, and terminations are basic to any signal integrity analysis tool. Modeling tools convert electrical information in semiconductor databooks into the necessary models or generate models from accurate measurements in the time domain.

As the third step, network solvers perform time domain analysis to determine the waveforms at the I/O pin or interconnect net, using as input electrical data produced by field solvers and the semiconductor models of active devices. Broadly speaking, there are two types of network analysis tools used in signal integrity analysis: those that rely on versions of Spice, and those that are based on direct-solution methods using fixed time increments. The complexity of solving the system of matrices that represents a large electrical network is an order of magnitude larger in an iterative, adjustable time-step method, like Spice, than in direct-solution methods. For the analysis of such large electrical networks as interconnects in a printed circuit or a chip module, direct-solution (non-Spice) network solvers give better performance. But for critical net analysis, Spice-based solutions are better because of the availability of very accurate transistor-level driver/receiver models.

Finally, for EMI analysis, interconnects are viewed as radiating antennas with alternating currents running through them. These currents are calculated in the frequency range of interest. Then the far and near fields radiated from these current elements are vector summed to determine the net radiated field.

The two biggest challenges in EMI analysis are obtaining driver/receiver models that are accurate to the frequencies specified by

Integrity Engineering, St. Paul, Minn.	Intusoft, San Pedro, Calif.	Mentor Graphics, Wilsonville, Ore.	Meta-Software, Campbell, Calif.	MicroSim, Irvine, Calif.	OEA International, Santa Clara, Calif.	OptEM Engineering, Calgary, Man., Canada	Performance Systems Integrity, Pittsburgh	Quad Design Technology, Camarillo, Calif.	Quantic Labs, Winnipeg, Canada	Zeelan Technology, Beaverton, Ore. (a), (b)
SimNetX	IsSpice3	BS500—XFX3D	HSPICE	Design Center	Metal—Henry and BUS-AN	Helmholtz—VLSI and ID	Psi-Boards	XTK—XFX3D	Greenfield—3D and Phidias	Model Lib
1993	1992	1991,1993	1989	1993	1988, 1991	1992, 1993	Q2, 1994	1988, 1993	1983, 1993	1993
2-D	—	2½- 3-D	—	2-D	2-, 3-D	2½-D	2-D	2½-, 3-D	2-, 3-D	—
Non-Sp.	Spice	Non-Spice	Spice	PSpice	Spice	Both	Non-Spice	Non-Spice	Spice	—
Yes	Yes	Yes	Yes	Yes	—	Yes	—	Yes	Yes	Yes
'What if' analysis	—	Schematic capture, layout, net ordering (c)	—	Schematic capture, analog, mixed-signal sim.	—	—	—	—	—	—
Yes/no	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes
No/yes	—/—	No/yes	—/—	No/yes	Yes/yes	Yes/yes	No/yes	No/yes	Yes/yes	Yes/yes
Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes	Yes/yes
Yes/yes	—/—	No/yes	—/—	No/yes	Yes/yes	Yes/yes	No/yes	No/yes	Yes/yes	Yes/yes
—	—	—	—	—	Yes	Yes	—	—	Yes	Yes
Yes	—	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	—
—	—	Yes	—	—	Yes	Yes	—	Yes	Yes	Yes
—	Yes	Yes	—	—	Yes	Yes	—	Yes	Yes	Yes
1, 2	7, 8, Mac	1–5	1–3	7(Windows)	1, 2	1 (Sparc), 7	1	1–9	1, 3, 4, 5	
Yes	—	Yes	Yes	—	—	—	Yes	Yes	Yes	Yes
Yes	—	—	Yes	—	—	—	Yes	Yes	Yes	Yes
Yes	—	Yes	—	—	—	—	—	Yes	Q4, '93	—
—	—	—	Yes	—	—	—	—	Yes	Yes	Yes
—	—	—	—	—	—	—	—	Yes	Q4, '93	—
—	—	—	Yes	—	—	—	—	Yes	—	Yes
—	—	—	Yes	Yes	—	—	—	Yes	Yes	Yes
—	—	—	—	PADS, PCAD	GDSII, CIF, DXF, Gerber	GDSII	—	PADS, PCAD	SDRC, ProEngineer	—

CIF = common interface format; DXF = autocad data exchange format; GDSII = graphical display system II.

(d) 1 = Sun; 2 = Hewlett-Packard (HP); 3 = HP/ Apollo; 4 = Digital Equipment; 5 = IBM RS6000; 6 = Data General; 7 = PC; 8 = MIPS; 9 = Silicon Graphics.

the applicable EMI guidelines, and analyzing the effects of enclosure on the radiated energy.

A number of these tools for signal integrity analysis are commercially available [Table 1]. The field solvers provide electrical models for interconnects and the coupling between them. Most of them provide accurate models for interconnects with transverse electromagnetic (TEM) or quasi-TEM modes of signal propagation. More sophisticated field solvers can handle 3-D structures like interconnects on hashed ground planes, and packages or other structures that have non-TEM modes of signal propagation, and will treat them with full-wave equation representation.

The integration of these tools with layout, design entry, and other simulation tools is critical to a productive design environment for signal integrity analysis.

For design of high-speed boards or modules, designers control the impedances of the interconnect traces by taking care to select and maintain the proper trace width; select appropriate transmission line configurations (such as stripline and microstrip line); and optimize dielectric constants and thicknesses. If the characteristic impedance of interconnects is matched with that of the terminating drivers and receivers, weaker signal reflections occur on the interconnect. A variety of terminations (series, parallel, Thévenin, RC network, and diode) can be used to minimize the signal distortion due to reflections, which they do by providing better impedance matching to the characteristic impedance of the interconnect.

2. How semiconductor logic families compare

Logic family	Typical propagation delay, ns	Edge speed, ns	Noise margin, mV	Signal swing, V	Operating voltage, V	Critical interconnect length, cm
CMOS	25	15	1000	4.7	+5	10.0
HCMOS	8	6	1120	4.7	+5	4.0
ACMOS	5	4	1250	4.7	+5	2.7
FCTCMOS	4	2	800	3.0	+3.3	3.5
TTL (H-,LS-, ALS-, S)	6, 9, 4, 3	3	300	3.0	+5	2.0
ASTTL	2	1.2	300	3.0	+5	1.0
Fast TTL	2.5	1.2	200	1.7	+3.3	2.0
ECL 10KH	1	1.8	230	1.0	–5.2	1.2
BiCMOS	1.2	0.7	200	1.0	+5	0.5
ECL 100K	0.8	0.5	200	1.0	–5.2	0.3
GaAs 10G	0.3	0.15	100	1.0	–5.3 & +3.5	0.1

ALL IN ORDER. While the minimum-wire method is widely used to route the traces on traditional boards and MCMs, at higher speeds, the order in which nets are connected can interfere with the delay budget—or rather, with the ability to stay within that budget. Daisy chain net ordering is one of the most usual methods, although other net orders can be used in particular designs.

Net ordering leads to a need for tight coupling between logical and physical design processes for high-speed applications. As a result, the interconnects' physical design properties (like termination rules, net ordering, and interconnect layer definitions) and electrical parameters (like their characteristic impedance and propagation delay) may be defined and analyzed at both the logical and physical design levels.

A concurrent design approach, if it has closely linked logical and physical design environments and is combined with signal integrity analysis point tools, has another plus: it helps electrical and physical layout designers to communicate and shortens high-speed-design cycle time as well. Such a system may have different design tools running on different platforms (depending on computational requirements), all operating from a consistent database and framework and sharing design data among themselves as appropriate [Fig. 4]. When design software operates in such harmony, under similar user interfaces, the electrical designer can more easily analyze basic design tradeoffs among many parameters—high-speed propagation delay, signal distortion, crosstalk, controlled interconnect impedance definition, termination schemes, and electrical net ordering rules—at the schematic level or at the layout level. And information can be shared by the design tools in both environments.

A concurrent design setup also integrates tools for analyzing such high-speed design issues as signal overshoot and undershoot, clock skew and jitter, ground bounce, differential pair routing, and shielded routing, not forgetting simultaneous switching effects and heat generation and dissipation.

As the number of high-speed nets in electronic systems increases, it will no longer be practical to analyze every net individually, or to specify termination rules, net ordering, and other constraints on individual nets. Future design tools will therefore need some intelligence if they are to assign net ordering and termination schemes on the basis of user-defined constraints on timing delay and the timing budget. These requirements will lead to layout synthesis and timing-driven routing. Nonetheless, it will always be necessary to conduct a careful analysis of some critical nets in high-speed designs.

TO PROBE FURTHER. One of many good texts on analysis and modeling of transmission line structures is *Monolithic Microwave Integrated Circuits: Technology and Design* by this article's author (Artech House Inc., Boston, 1989). Another is *Transmission Lines, Circuit Analysis, Simulation and Design*, edited by A.E. Ruehli (North-Holland, 1987). *Numerical Computation of Electric and Magnetic Fields*, by Charles W. Steele (Van Nostrand Reinhold Co., 1987), is a good collection of numerical methods commonly used to solve Maxwell's equations.

Multichip Module Technologies and Alternatives: the Basics, by editors Daryl Ann Doane and Paul D. Franzon (Van Nostrand Reinhold, 1993), includes high-speed design issues in MCMs. ◆

ABOUT THE AUTHOR. Ravender Goyal (SM) is a product manager at Mentor Graphics Corp. Previously, he worked at Anadigics Inc. on GaAs-based telecommunications circuit and technology development. He has coauthored many papers and two books, and was the guest editor of the September 1990 issue of the IEEE Microwave Theory and Techniques Society's Transactions.

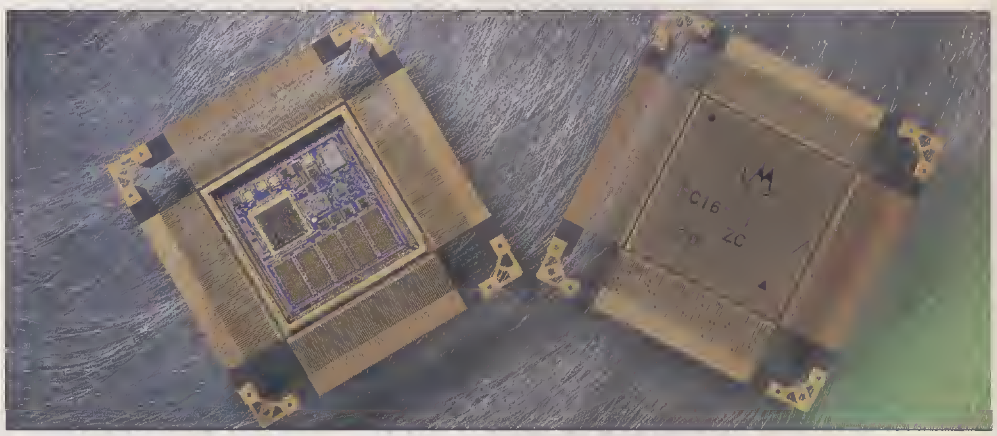
Diagnosing high-speed effects

When transmission-line effects are not properly accounted for, printed-circuit boards and multichip modules slated for high-speed applications may function erratically, if at all. Some of the more common symptoms are listed below.

- The board or multichip module functions only at low clock speed.
- The board or the multichip module operates properly only within a narrow range of frequencies.
- The system operates properly with parts from one vendor but not with another's parts.
- The system functions with parts from one batch but not from another.
- The board or module works when cooled or when heated, but not over the specified temperature range.
- The board works with certain connectors or with parts in certain packages but not with others.
- The board or multichip module is sensitive to small changes in power supply voltages.
- Touching or bringing the hand closer to the board or multichip module changes the shape of the signal.
- Adding bypass capacitors changes the operation significantly.
- The board or module has significant electromagnetic radiation, or is sensitive to electromagnetic interference.
- The board or module operates properly as an individual subsystem, but not when connected with other system components.

Testing multichip modules

In many cases, applying board-type tests using an IC tester will prove to be the most effective test methodology



[1] While simple multichip modules needing no repair can be tested by conventional chip-testing methods, more complex ones, like this demonstration military computer system, require that a board-test strategy be used. The module contains a 68040 microprocessor, a programmable gate array, and five memory chips, in addition to many smaller components.

The advantages of implementing electronic systems as multichip modules instead of boards full of packaged ICs are well known. The compact assemblies of uncased chips and other tiny components are simultaneously smaller, lighter, more reliable, and sometimes even faster than their printed-circuit board counterparts. Less clearly perceived are some puzzling challenges that multichip modules pose, many of which are tied to testing the compact assemblies.

Since multichip modules (MCMs) tend to combine the complexity of printed-circuit boards with the access problems of ICs, testing them can be quite a challenge, to say the least. Successful test strategies borrow heavily from conventional chip and board test methods—often combining them for best effect. Which test procedures are most appropriate for a given MCM depends, of course, on the characteristics of the particular module. Relatively simple ones that are not intended to be repairable are best treated as chips; complex devices that must support repair [Fig. 1] are more appropriately dealt with as boards.

Andrew Flint Motorola Inc.

Whatever the ultimate strategy, it will probably be put together in three phases: deciding what tests to perform, developing test vectors to support those tests, and applying the vectors on test equipment. Since MCMs are frequently produced by semiconductor fabricators who already own expensive very large-scale IC (VLSI) testers, practical test strategies in many cases will consist of applying board-type tests using chip-type automatic test equipment.

MCM test approaches tend to be rooted in either IC testing or board testing. The former basically consists of full functional test using the MCM package pins for access. Part of the appeal of the full functional approach is that the vectors it needs can often be derived from the design verification simulation stimulus. In addition, using a chip tester as the test platform would allow MCM functionality to be fully exercised in only a few seconds.

Less desirably, if a faulty wire bond existed on the module, the chip tester would be unable to provide fault diagnostics to support a repair requirement, since chip test is basically a go/no-go operation. Also, an MCM may contain several passive analog components, which are difficult, if not impossible, to test on chip testers. For these reasons, functional test using a chip tester is best suited for simple, nonrepairable MCMs.

The other MCM test methods are borrowed from board test. In many cases the typical two-step board test strategy of assembly test followed by system test can be readily applied to MCMs. Assembly test includes such techniques as in-circuit testing, boundary-scan testing, and limited functional testing.

In-circuit test applies vectors to chips in isolation from their neighbors. Such testing obviously requires that certain design-for-testability practices be followed—for example, bringing the I/O pins on each internal die to external access points, making sure that the input pins of the internal dice are driven by three-state outputs, and never hard-

Defining terms

Application-specific integrated circuit (ASIC): a chip providing customer-required functionality by using customized metal layers over a standard array of circuitry.

Assembly test: a test that detects such manufacturing defects as wrong or misaligned parts and open or shorted component leads.

Boundary scan: a test practice in which special circuits are added to the input and output signals of ICs to gain controllability and observability at the board test level.

Burn-in: acceleration of device failure modes by operating at elevated temperature.

Fault diagnosis: precise identification of the cause of a test vector failure.

Fault dictionary: (for failing test vectors or output signatures) a list of probably responsible faults.

Functional test: a test conducted from the I/O pins of the device under test.

In-circuit test: a test in which the tester gains access to the internal nodes of the device under test, typically through a bed-of-nails fixture.

Known-good dice: unpackaged integrated circuits that have been fully tested.

Level-sensitive scan design (LSSD): a design practice in which test structures are added to a chip's internal state elements to facilitate automatic test pattern generation.

Limited functional test (for multichip modules): a functional test in which test resolution is limited to exercising the I/O pins of the ICs within the multichip module. No effort is made to exercise the gates internal to those ICs.

Pin level stuck-at test: a test used to verify that a component's leads are connected to the substrate.

System test: a test of an assembly run in an actual system or in a close approximation of the system.

Test vectors: patterns of 1s and 0s applied to chips' inputs with expected output response.

Wafer probe: a test of integrated circuits while still in the silicon wafer manufacturing stage.

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wiring internal signal pins to power or ground. The biggest hurdle to the widespread use of in-circuit test is the fact that tester control of internal circuit nodes will be impossible if these practices are not followed.

BOUNDARY SCAN HELPS. As with boards, however, boundary scan can provide a solution. If MCMs are designed with as many boundary-scan chips as possible, the access problem will be lessened. Currently available chips that comply with the IEEE 1149.1 boundary-scan standard include advanced microprocessors, application-specific IC families, specialty chips, and bus transceivers. Using boundary scan, MCM interconnect can be verified with only thousands of vectors, as compared with tens of thousands of vectors without it.

Among the most important uses of boundary scan is verifying the assembly of an MCM onto a circuit board. Unfortunately, it can do this only if all the MCM I/O pins are internally connected to boundary-scan chips. Adding boundary-scan components to the chip module for the sole purpose of more easily verifying its attachment to its host circuit board may therefore well be worth consideration.

The final assembly test technique is limited functional test, which exercises the chips in the MCM only enough to toggle their I/O pins. While this is certainly not trivial, it is much easier than trying to propagate vectors from the package's I/O pins all the way to the internal gates of those chips. Limited functional test is best suited as a supplement to other assembly test techniques and as a stand-alone test only when in-circuit and boundary-scan tests are impossible. In some cases, because of the nature of MCMs as a hybrid between chips and boards, hybrid test combining several techniques is appropriate.

As mentioned earlier, in testing boards, assembly test is usually followed by system test. For MCMs, system test means plugging the module into a circuit board, where the overall functioning of the MCM can be verified at speed in midflight, so to speak.

Besides serving as part of a two-step testing strategy, system test can also be a stand-alone strategy when the fault coverage and diagnostic resolution are outstanding or when a module is simple and needs no repair.

TEST SELECTION. Before deciding on a test strategy for an MCM design, a multitude of factors must be considered. Among the more crucial are the costs of both the individual dice and the finished product, the speed of operation of the product, the thoroughness with which the dice were tested before assembly, and the availability of simulation models and test vectors for the dice. Also important are the type of tester available, the cost of test time, the complexity of the MCM, repair requirements, and the quality needed for the finished product. Other prime considerations are the number of modules to be shipped, the degree to which the module has been designed to be testable, the degree to which the dice have been designed to be testable, the percent of nodes accessible to a tester, burn-in requirements, and the availability of system test.

No recipe has yet been developed for converting the parameters just enumerated into the best possible test strategy for a given MCM design. Common sense, rules of thumb, and experience are the best guides right now. Some of this practical know-how has been combined into a selection chart that, while unable to determine which of several strategies is best, does at least eliminate the impossible ones [Fig. 2 on p. 62].

Next, after a first-order identification of

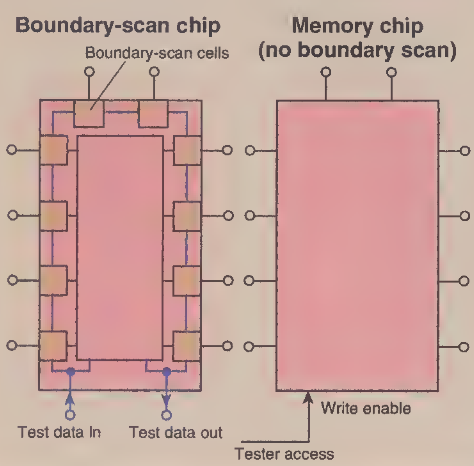
Chip and board testing

The standard method for testing integrated circuits is full functional test on expensive, high-speed automatic test equipment (ATE), like the Trillium tester from LTX Corp. shown in the photo. In IC testing, the goal is to prove the functionality of the chip by having the test vectors exercise all of its internal gates.

Verification that the part meets its basic dc specifications is handled by a parametric measurement unit on the tester. To confirm that such ac parameters as propagation delay are within specification, high-accuracy timing measurements are also performed. Most test problems are solved by this highly capable test equipment, which makes possible test speeds of over 100 MHz and is capable of providing a million vectors from the tester's memory.

To increase the yields of packaged dice, most IC manufacturers pretest their chips while they are still in wafer form. Wafer probing is typically done with the same test equipment as final testing, but with different fixturing. State-of-the-art probe fixturing can accommodate high-speed testing, but most wafer testing checks only functionality and dc parameters. Testing for ac parameters is done at final test, often for speed sorting.

Test vector generation, though, remains the biggest technical issue in IC test. Some integrated circuits—application-specific ICs (ASICs), for example—have simulation libraries available to support an advanced design verification environment, out of which the tools needed for test vector generation naturally develop. But advanced microprocessors lack the same inherent simulation support that ASICs have because the custom microprocessor circuits are not contained in built-in libraries. These chips require tremendous amounts of manual test vector generation, with much of the simulation modeling done on the fly.



One method for reducing the test generation effort is to design the chip to be testable right from the outset through the use of such techniques as level-sensitive scan design (LSSD). In this method, all device state elements are connected in a scan chain to allow serial application of test vectors. The advantage of using this method is that algorithms are already in place to generate test vectors for such circuits automatically.

Another technique designed to reduce the post-design test effort is built-in self-test (BIST). BIST places within the chip special circuits that exercise internal logic and verify functionality, and is usually designed to rapidly perform an at-speed test of the part.

BOARD TEST STRATEGIES. Assembling components onto printed-circuit boards successfully requires verification through complete test of every unit. For boards with hundreds of components, this job cannot be done effectively with a single test. Procedures that test a board's functionality from its primary I/O connections cannot isolate such faults as missing pull-up resistors and open surface-mount connections. On the other hand, tests that are good at detecting missing components and open connections cannot determine if a board will perform its function at speed. To handle this dilemma, loaded boards are tested in two steps: assembly test followed by system test.

In assembly testing, each component is checked to verify its correct connection to the substrate. This in-circuit test technique requires tester access to each circuit node. Typically, access is achieved with a bed-of-nails test fixture designed for a specific circuit board. The nails are spring-loaded test probes contacting vias, edge connector pads, and through-hole component leads.

Assembly testing is done in several steps. Shorts testing and passive analog tests are performed without power applied to the board.

possible strategies, comes a detailed analysis of the MCM, including the many other parameters already mentioned. Ideally, this analysis is performed at an early stage in the design cycle of the module, so design improvements can be put into effect to improve test coverage or reduce the overall system cost.

To get a feel for the kind of thinking that goes into selecting a test strategy, consider a multichip module with the following characteristics: it runs at 50 MHz and contains uncased ICs (two RAMs, one custom chip, and one digital signal processor) that do not support boundary scan. The MCM technology does not support repair, and the IC dice are pretested but not burned in. While in-circuit test cannot be performed, a system test is feasible. And simulation to support functional test on a chip tester is possible but difficult because the module is complex.

In this case, a first-level analysis using the chart of Fig. 2 shows that chip-type functional test and board-type system test are possible test methods. Functional test, though, is not a good stand-alone strategy for this MCM because of the complexity of the assembly of chips: test vectors could not be developed in a reasonable amount of time. On the other hand, a limited functional test can be developed, which will cover all the dice pins.

System test is usually poor as a stand-alone test because it will not detect or diagnose many manufacturing defects. But it is unmatched at showing how well a component functions at speed.

From these considerations, and also noting that the chips are not burned in, the recommendation is a three-stage strategy, in which a limited functional test is followed by a system test, a burn-in step, and a second system test. The first two tests cover all the faults likely to occur in the product. The burn-in and second system test then weed out those units that would have failed after a short while in the field.

Chip versus board testers

Parameter	Board tester	Chip tester
Number of channels	1500	256
Vector depth	16 kb	1 Mb
Speed, MHz	5.0	40
Backdrive capability, mA	500	50
Diagnosis capability?	Yes	No
Boundary-scan ATPG?	Yes	No

ATPG = automatic test pattern generation.

DEVELOPING THE TEST VECTORS. Once a test strategy has been chosen, the next task is to develop test vectors. For boundary-scan and in-circuit tests, vectors can usually be generated automatically by modern board-testing systems. Functional tests, however, will almost always require that at least some vectors be written manually.

Another way of obtaining in-circuit vectors is to buy them from the IC manufacturer. The manufacturer's vector set is likely to be extremely lengthy, but will provide very complete fault coverage. Depending on tester memory limitations, only the first several thousand vectors obtained may need to be run.

In the case of the MCM described in the previous section, test vectors were developed in two steps. The functional vectors, which may be thought of as performing a combination of limited functional test and built-in test, were developed manually in a simulation environment to prove correct-

Then each IC is tested by itself with power applied. For complex chips, the ratio of gates to pins is high, and tests for pin level connections often test only a small portion of the chip's workings. For this reason, the in-circuit test step assumes that chips are fully tested before assembly.

In the days of dual in-line chip packages, bed-of-nails access to each circuit node was automatically achieved by contacting through-hole leads on the bottom of the board. With the advent of surface-mount technology and densely packed double-sided boards, the access required by bed-of-nails in-circuit testing has been difficult to justify. To deal with this situation, boundary scan was developed.

BOUNDARY BASICS. Boundary scan is a test practice in which direct tester access to each circuit node is not required. Instead, special test structures are designed into the ICs to allow virtual test access from the board edge connection.

The special test structures consist of a shift register made up of flip-flops at every I/O lead of the device and a state machine to control the test circuits. By concatenating the shift registers added to each chip into one chain for the whole board, test vectors can be shifted into the board circuitry from the edge connector.

When all chips on a board have boundary scan, all chip-to-chip interconnect can be readily tested. With the assumption of pretested ICs mentioned above, a board passing a boundary scan interconnect test is analogous to a board passing in-circuit test using a bed-of-nails tester.

In addition to interconnect testing, other uses for boundary scan are chip internal testing (scanning serial patterns into the chip and scanning out the chip response) and sample testing during normal operation (sampling outputs at certain times during operation). Of course, boundary scan is a digital technique, so it does not apply to analog circuitry, but work is under way to extend the concept to allow simplified testing of analog components, too.

The impact of boundary scan has been immense. Automatic test equipment is available with hardware and software designed to support it. So many chip suppliers now provide ICs with boundary-scan circuitry on them that it is possible to design a complex circuit board in which most of the chips are compatible with the IEEE 1149.1 boundary-scan standard.

Although the main obstacles to full compatibility are memory

devices and small-scale integration (SSD) chips, these can be tested for pin faults using the boundary-scan chain of neighboring devices, as shown in the drawing. True, a certain amount of automatic test equipment access may still be required—to operate the strobe signals at the proper times, in the illustrated case—but providing that access is much simpler than providing access to all the memory's address and data lines.

Once a circuit board has passed assembly test, a high-speed system test is performed—typically by a custom test box—to ensure that the board works properly at its intended operating speed. The defects that can slip through after component prescreen and assembly test include marginal components, components damaged during handling by such things as electrostatic discharge, and assembly defects not covered by in-circuit test.

Fault diagnosis is needed to support the repair of system test failures. But fault diagnosis can be complex because it may be extremely difficult to determine the cause of system test failures when the causes are subtle. Techniques such as guided probing and fault dictionary are aids to reduce the complexity. Newer approaches include providing a self-test driven by an on board microprocessor. But no matter how good the diagnostic resolution, there will always be faults whose diagnosis requires trained technicians armed with logic analyzers.

ness before application on the test floor. Support for the self-test was provided by the on-board digital signal processor (DSP) component.

Vectors for the system test were borrowed largely from the test code for the board that the MCM replaced. In all likelihood, a common technique for developing MCM test code will be to adapt board-level system tests to MCM testing, especially when part of an existing board's circuitry is placed into an MCM.

APPLYING TEST VECTORS. The final step in the test development process is to decide how to apply the test vectors. Because many MCM producers are also chip producers and already own expensive VLSI IC testers, there is a great deal of interest in using those machines for testing MCMs.

			N				Y				Simulation?
			N		Y		N		Y		Boundary scan?
System?	Known-good dice?	Repair?	N	Y	N	Y	N	Y	N	Y	In-circuit?
N	N	N	0	3	0	3	1	1 3	1	1 3	
		Y	0	3	0	3	0	1 3	0	1 3	
	Y	N	0	3	2	2 3	1	1 3	1 2	1 2 3	
		Y	0	3	2	2 3	0	1 3	1 2	1 2 3	
Y	N	N	4	3 4	4	3 4	1 4	1 3 4	1 4	1 3 4	
		Y	4	3 4	4	3 4	1 4	1 3 4	1 4	1 3 4	
	Y	N	4	3 4	2 4	2 3 4	1 4	1 3 4	1 2 4	1 2 3 4	
		Y	4	3 4	2 4	2 3 4	1 4	1 3 4	1 2 4	1 2 3 4	

[2] This charting tool for identifying possible multichip module (MCM) test methods requires that six questions be answered: 1. Is a system test available? 2. Are known-good dice available? 3. Does the MCM technology allow repairs to be made? 4. Is simulation feasible? 5. Do any of the dice in the MCM support boundary scan? 6. Is in-circuit test feasible? The answers to the two groups of three questions yield one vertical and one horizontal line. The box in which they intersect contains the recommended test strategies, as follows: 0 = no test capability; 1 = functional test; 2 = boundary-scan test; 3 = in-circuit test; and 4 = system test. (Chart developed by William Blood Jr.)

Fortunately, even though chip and board testers are quite different [see table on p. 61], two of the board-type tests—in-circuit and boundary-scan—can indeed be applied on chip testers. Certain rules must be followed, however, to avoid problems with using a tester not specifically designed to support these methods. The main issues are vector sources, IC isolation, and diagnostics.

For in-circuit testing, the main concern is that the test vectors be developed in the proper format for the IC tester. Board testers have pattern libraries that support many common IC types; chip testers do not. So the vectors will have to be generated manually or obtained from the chip manufacturer—much the preferable alternative.

The second major issue is IC isolation. In-circuit test exercises each chip individually, so its neighbors must somehow be put out of the picture. Board-test generation software automatically dispenses disabling patterns to put neighboring chips with three-state outputs into their high-impedance state; or, for parts that do not have three-state outputs, it forces neighboring outputs to a logic HIGH for subsequent overdrive to a LOW by the vectors.

Chip testers have neither the software to automatically generate isolation patterns nor drivers strong enough to overdrive logic states. The driver-strength constraint requires that all outputs on internal nodes be of the three-state type. For lack of software support for generating disable patterns, that chore must be done manually. The designer must determine which ICs may interfere with the chip under test, and then add vectors to put their outputs into the high-impedance state.

A popular technique in testing boards is to develop a set of vectors that puts all the devices on one into the high-impedance state, and then to bring only the device under test out of that state. This general initialization routine can be inserted at the beginning of all device tests.

Diagnosing in-circuit test failures is another challenge. Chip testers do not automatically assist in assigning failures to a particular fault. But they can be coaxed into providing a fair amount of diagnostic help.

One method is to expand their binning systems. In normal chip testing, failed chips are assigned one of several categories, or bins, depending on which test they failed. For MCM testing, additional bins could be created to classify failures based on which chip failed.

Another viable method of fault diagnosis is the use of a fault dictionary—a look-up table that lists vector failures and probable causes. Chip testers can compile vector failures in a datalog, which lists the failing vectors by vector number along with failing output numbers. With a fault dictionary, look-up software would match the failing vectors in the datalog with faults in the dictionary to produce a diagnosis. The dictionary itself should be developed the same time that the test vectors are written.

A final method is probing. With board testers, when an in-circuit test fails, power to the device is removed and the operator is prompted to draw a grounded probe across the device leads. The tester monitors the probing to see whether any device leads are open, that is, that they are not contacting the substrate. This approach serves as a simple and effective means for isolating failures to ordinary assembly faults.

The same technique could be used on chip testers if three conditions are met: the tester software and hardware can be made to support the process, sufficiently fine probes can be obtained (devices used in MCMs have extremely fine pitches), and operators or robots can be trained in the delicate task.

Boundary scan, though originally intended to alleviate board test problems, may also be applied to MCMs on chip testers. The important issues are test vector generation and fault diagnostics. Typical chip testers lack the tools to support boundary scan test generation and diagnostics. But there is, after all, an IEEE standard for boundary scan and the test structures are independent of a chip's internal logic, so if the designer learns how to generate tests and diagnose faults for boundary-scan interconnect for one MCM design, the work on subsequent designs will be relatively simple.

This means that manual boundary-scan test generation for small MCMs is practical. A fault dictionary to support diagnostics can also be constructed manually in not too much time.

To sum up, the chosen test strategy can usually be applied with existing equipment. In certain cases, tester limitations may force the adoption of a less-than-optimal test strategy. It seems reasonable to expect the future to bring testers optimized for MCM designs—testers that will always allow the adoption of the best strategy for a given design.

TO PROBE FURTHER. A good introduction to the important aspects of multichip module (MCM) testing can be found in "Electrical Testing of Multichip Modules," by T.C. Russell and Y. Wen, chapter 13 of *Multichip Module Technologies and Alternatives*, edited by P.D. Franzon and D.A. Doane (Van Nostrand Reinhold, 1993). In J.K. Hagge and R.J. Wagner's "High-Yield Assembly of Multichip Modules Through Known-Good ICs and Effective Test Strategies," *Proceedings of the IEEE*, Vol. 80, no. 12, 1992, pp. 1965–94, the effects of dice yield on MCM yield are examined.

C.M. Maunder and R.E. Tulloss have edited *The Test Access Port and Boundary Scan Architecture* (IEEE Computer Society Press, 1990), the definitive text on boundary scan. In the past few years, the International Test Conference has steadily increased the number of papers and tutorials concerning MCMs. Conferences devoted to the subject include the International Conference on MCMs, hosted by the International Society for Hybrid Microelectronics and the IEEE MCM Conference. ◆

ABOUT THE AUTHOR. Andrew Flint (M) develops, implements, and supports MCM test strategies for Motorola Inc.'s commercial-plus technologies operation in Tempe, Ariz. Earlier he was a board test engineer with Digital Equipment Corp. His interests include developing automatic test program generation (ATPG) software and hiking in the desert.

Engineering a small system

Once the preserve of large government projects, systems engineering can benefit commercial products, as well

"Do it right the first time" is the slogan of systems engineering. The approach can benefit all types of development projects, small as well as large, because the objective is the same: to design a high-quality product as fast and efficiently as possible.

Perhaps the most cogent definition of systems engineering is given in the *1988 Chambers Science and Technology Dictionary*: "A logical process of activities which transforms a set of requirements arising from a specific mission objective into a full description of a system which fulfills the objective in an optimum way. It ensures that all aspects of a project have been considered and integrated into a consistent whole."

In other words, systems engineering translates a customer's stated need into a set of requirements and specifications for a system's performance and configuration. The process defines all the resources and special tools needed plus the stages in the product's development. It also sets up checkpoints at each stage in the design cycle to ensure that objectives are met and that defects are identified and corrected as early as possible, thus minimizing their impact on the development schedule and on the product's cost and quality. The final system is then validated against the original requirements and specifications.

For decades now systems-engineering techniques have been standard in the U.S. Department of Defense and applied to large commercial products like airliners. But they have not been widely applied to the engineering of medium-sized or relatively small commercial products like medical diagnostic equipment or industrial test and measurement instruments. That situation, however, may be changing. Organizations such as the U.S. Food and Drug Administration (FDA) and the International Organization for Standardization (ISO) are establishing guidelines—for example, the ISO standard 9001—on how quality should be addressed during the development of products. A development process based on the analytical techniques of systems engineering also can help meet this goal.

Kurt Skytte AnalySys Consulting Inc.

START WITH NEEDS. Perhaps the prime assumption underpinning systems engineering is that a product should be designed to fulfill customers' actual needs; only by solving a real problem better than any competition does a product become truly successful. As identified through marketing surveys and other mechanisms, the customers' needs inspire the formal written requirements the product must fulfill. On those requirements are based the system's technical specifications, which form part of the documents that are the key references for the design.

Self-evident as this approach may seem, it is surprisingly common for companies to develop products with little or no customer input. Even when a large market exists, a product can fail when the customer's real needs are poorly understood. For example, both General Electric Ultrasound in Milwaukee, Wis., and Philips Ultrasound in Santa Ana, Calif., have introduced ultrasound medical imaging instruments that would have sold in greater numbers had the interfaces been better tailored to the needs of the intended users. The GE product put a touch screen over the image monitor—but imaging gel and other contaminants on the ultrasound technician's fingers quickly accumulated, smudging the screen and blurring the diagnostic image.

The problem with the Philips instrument was different. Ultrasound imaging instruments typically have many separate controls, and Philips sought to reduce that number by incorporating a mouse. But ultrasound technicians want to concentrate on the diagnostic image, not be distracted by computer icons, and to progress through an examination as quickly as possible. Clicking the buttons on the mouse was neither fast nor interactive enough to suit their needs.

REDUCE REDESIGN. Another assumption behind systems engineering is that the system as a whole must be carefully planned out to minimize its redesign. For a long time the largest source of project delays, redesign typically becomes necessary because the product requirements were poorly defined or changed, the engineering specifications were inferior, or the basic design's ability to meet the original requirements was not thoroughly reviewed.

The full effect of inadequate planning is rarely detected until late in the development cycle, sometimes even into the system's design validation phase. The later any design defects are detected, the more time and money any redesign will need. Moreover, late changes often compromise the product's reliability and maintenance costs, perhaps even affecting its profitability and success. Spending extra time up front completing and clarifying the basic requirements always pays high dividends in the end.

Even so, the best-written requirements can be undermined if unnecessary changes to them are allowed after design is started. During this phase, the product is often embellished in ways not specified originally. Commonly called "creeping elegance," these additions are sometimes made without an awareness that such changes may delay the schedule and add to the life-cycle costs.

In Japan, such companies as Matsushita Communication Industrial Co.'s Instrument Division in Yokohama and Toshiba American Medical Systems Inc. in Tustin, Calif., manage both to prevent and profit from creeping elegance. As new ideas or requirements surface, they are collected not for ongoing projects, but for later upgrades or new products.

To be sure, companies must at times react to market shifts or exploit some new discovery by changing product requirements, but the resulting stretchout of schedule and increase in cost should be clearly grasped and properly integrated into the product's development plan.

SPECS DRIVE DESIGN. A third essential assumption of systems engineering is that specifications for the system as a whole, as well as for the details of individual components, should direct the design process. A system-level design specification defines the system's architecture in terms of functional segments and their interfaces. Taking the time to architect the system properly can minimize the system's complexity, lower its cost, and improve its reliability, manufacturability, and serviceability. It is also important for the final top-level design and architecture to show how these objectives can be balanced in terms of life-cycle costs, not near-term objectives.

Performance specifications must also be captured so that they can be compared with measured system performance during design verification.

SCALING DOWN. Systems engineering on large government projects is rigorous and detailed. For smaller commercial applica-

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tions, it can be streamlined to reduce the overhead while retaining the benefits.

Whatever its size, though, a company using systems engineering development must proceed through six phases: requirements development, system design, detail design, system integration, system optimization, and design validation. During each phase, formal documents are written, capturing all elements of the design. These documents then become the references that drive the design process.

Phase 1: Requirements development. The first step in designing any system is identifying the objectives it must fulfill. Since life-cycle costs hinge on this early planning, enough time and resources absolutely must be allocated to researching the system's requirements.

In a commercial environment, the product's objectives should be determined by surveying the needs of potential customers. Next, a team should be formed to develop the specification describing the product's functional requirements. This team should include representatives from marketing, engineering, manufacturing, field service, and any other group that will influence the system's functions and life-cycle costs.

The specification should cover each of the system's required functions in detail, including a description of the user interfaces with objectives for response time, types of input and output devices (visual or auditory), and any application-specific information that relates ergonomic requirements to the typical user's environment. Each function must be associated with a specific type of control, and each requirement for user feedback must be associated with an output device. The functional-requirement specification, however, defines only *what* has to be designed into the product, not *how* it is to be designed.

One of the trickier aspects of this first phase is determining which features and functions are of the most value to the product. The first draft of a functional specification for a new product often resembles an indiscriminate list of features found in existing products. One way to identify the most valuable features is to use quality function deployment (QFD), a technique that—through developing a series of matrices—can help rank product attributes in order of their importance to the customer. Understanding which of these attributes matter most will aid the team in making sound decisions when tradeoffs must be made.

The functional-requirement specification is complete when the project team is willing to commit itself to a set of functions, recognizing that the completeness of the document describing them is vital to the quality of the final system, and that any changes made to the document after it is released to the design engineers will directly affect product quality, production schedule, and life-cycle costs.

Phase 2: System design. The next step is to translate the completed functional requirements into an architecture and a set of system-level design specifications that together meet the original customer needs. It is essential now to translate all the functional requirements into design specifications, making sure that none is overlooked.

The architecture document must identify each subsystem and component, specify all the intended relationships among them, and delineate clearly how each will fulfill one of the documented functional requirements. Performance requirements should be specified quantitatively, in terms that can be measured in the final system.

For any small project, such as an instrument containing only a couple of circuit boards, writing a single system-level specification may suffice. For a larger project, such as a medical ultrasound imaging system, it is preferable to have one top-level document specify the system's architecture and performance requirements, and separate specifications define the functional and performance requirements for each subsystem. The subsystem specifications would also identify and specify the requirements for each circuit board within the subsystem.

One of the more perplexing aspects of the system-design phase is the proper allocation of functions to hardware and software. If that allocation is suboptimal, the product may end up with overly expensive hardware or overly complex software. For an intricate system such as an ultrasound imaging system, computer-aided engineering (CAE) tools are useful for comparing choices of implementation, developing critical performance specifications, and verifying signal-processing algorithms before starting the designs of subsystems and components.

Ideally, a single simulation tool would address all the necessary levels of simulation from behavior modeling through algorithm development and down to the level of hardware details. But currently, different CAE tools must address those needs [see table at right]. Any modeling or simulations begun during this phase should be revisited later to optimize the system's performance.

Part of the system-design phase is to develop a plan for the integration of the system. This plan should define the order in which the components will be assembled into larger units, whose function will be verified before proceeding to the next step in the assembly. The plan should identify the acceptance criteria for hardware (such as printed-circuit boards and other components) and software for those units, identify any needs for special test fixtures or tools, and assess the number of support personnel required to complete the assembly.

For more complex systems, a coordinated

Systems-engineering checklist

Here is a checklist of the steps essential to applying systems-engineering principles to the design of smaller commercial products:

Requirements phase

- Consult potential customers to ascertain their actual needs.
- Have a multidisciplinary project team take that statement of needs and use it to develop a detailed specification describing the product's functional requirements.

System-design phase

- Develop a system architecture that supports specified product requirements.
- Develop system-design specifications that document the system's architecture, system-level performance specifications, and the functional requirements of each subsystem and component.
- If necessary, use simulations and other analytical techniques to verify that top-level design concepts support all specified product requirements.
- Define the system's life-cycle cost model.

Detail design phase

- Design the hardware and software as described in the system-design specifications.
- Schedule several detail-design reviews to make quite sure that the hardware and software meet the specifications.
- Build and test each component to verify that the design objectives have been met.
- Develop plans for integrating the components and subsystems into the entire system, and for testing the system.
- Compare the actual costs of designing the hardware and software with the cost estimates to verify that cost objectives are being met.

System integration phase

- Integrate the components and subsystems into a prototype system and verify its functionality.

Design verification and optimization phase

- Verify that all performance specifications are met over all specified operating conditions.
- Optimize the system's design by minimizing any differences found between expected and measured performance.

System validation phase

- Evaluate the final product's configuration to ensure that it complies with the original functional-requirements specification.

test plan helps ensure that any special resources or equipment will be on hand to test and optimize the system. For efficiency, this plan should identify key performance benchmarks.

Phase 3: Detail design. Now, and only now, do engineers begin to design the hardware and software that will implement the top system-level specifications. Every aspect of these designs should be documented by drawings and written descriptions, which will ultimately support the development and manufacturing processes. From the detail-design phase emerge tested and verified components ready for integration into the system.

The design teams should use the system-level design specifications as the primary technical reference for all designs. Moreover, several times during the detail-design phase, the designs should be reviewed against the systems-level specification to see that its objectives are being met.

Phase 4: System integration. At last, it is time to put all the components and subsystems together. They should be assembled in the order defined by the integration plan, which was mapped out during the system-design phase, and verified to work.

Phase 5: Design verification and optimization. After it has been established that the system works properly, it is necessary to test that it performs just like or better than the requirements of the system-design specification. If the system was properly designed, the scope and range of the optimization parameters should be embedded within the control software or hardware so that adjustments are easy. The system is optimized when differences between the expected and measured performance of all its functions have been minimized.

Phase 6: System validation. Finally, it is time to ensure that the final system design complies with the functional-requirements specification. This is the last overall check of the system before its design is released to manufacturing.

Every state of the machine and every function described in the original functional requirements must be tested to validate the system. Since today most systems have some kind of embedded computer, functionality is usually dictated by the control software and much of the validation is bound up with the testing of the software design. Every time the software is modified or changed, the system must be re-validated. In fact, the ability to validate a system design quickly can enhance its upgradeability and maintainability. Automated test tools that can simulate user inputs and then monitor for correct responses can speed this process.

BEYOND CONCURRENT ENGINEERING. A well-conceived systems-engineering process shares some of the same development objectives as concurrent engineering. Premised on multidisciplinary project teams, concurrent engineering helps to ensure that all elements of the product life cycle are factored into the design, and overlaps development phases whenever possible to save time.

Tools for computer-aided systems-engineering design

Company	Product name	Development of requirements	Simulation and modeling	High-level software modeling and development	DSP simulations	Algorithm development
International TechneGroup Inc. Milford, Ohio	QFD/Capture	●				
Ascent Logic Corp. San Jose, Calif.	RDD		●			
I-Logix Inc. Santa Clara, Calif.	Statemate		●			
General Electric Co. King of Prussia, Pa.	OMTool			●		
Interactive Development Environments Inc. San Francisco	Software Through Pictures		●	●		
Popkin Software & Systems Inc. New York City	System Architect		●	●		
ProtoSoft Inc. Houston, Texas	Paradigm Plus			●		
Comdisco Systems Inc. Foster City, Calif.	SPW		●		●	●
Mathworks Inc. Natick, Mass.	Matlab				●	●
Mentor Graphics Corp. San Jose, Calif.	DSP Station		●		●	●
Signal Technology Inc. Santa Barbara, Calif.	NIPower		●		●	●

DSP = digital signal processing. Source: Kurt Skytte

In some ways systems engineering may be viewed as a refinement of concurrent engineering. It takes the basic concept of multidisciplinary design teams and adds to it guidelines for formal development phases.

By adopting a structured approach to development that is scaled to the needs of the project, it is possible to eliminate some of the remaining sources of design defects and development risks. Development time is further shortened, and product quality and profitability are enhanced.

TO PROBE FURTHER. Because the use of system engineering principles in developing modest-sized commercial products is a fairly new concept, information on it must be taken from more general systems-engineering sources. The National Council on Systems Engineering (NCOSE) has established a working group to specifically address commercial systems-engineering practices; contact NCOSE at 333 Cobalt Way, Suite 107, Sunnyvale, CA 94086.

Benjamin S. Blanchard and Walter J. Fabrycky's textbook *Systems Engineering and Analysis* (Prentice Hall, Englewood Cliffs, N.J., 1990) is an excellent overview of systems-engineering concepts, design methods, and commonly used analytical tools.

All aspiring system architects should also read Eberhardt Rechtin's classic *Systems Architecting: Creating and Building Complex Systems* (Prentice Hall, Englewood Cliffs, N. J., 1991), which defines the role and responsibilities of the system architect and lists what knowledge, skill, and other pertinent traits are required. Rechtin's article "The Art of Systems Architecting" *(IEEE Spectrum,* October 1992, pp. 66–69) introduces a number of design heuristics that can be used, along with analytical techniques, to develop the architectures for systems.

The author wishes to thank Michael Brendel and Christopher Chapman of Siemens Medical Systems Inc. (Ultrasound Group), Issaquah, Wash., for their helpful insights. ◆

ABOUT THE AUTHOR. Kurt Skytte is the president of AnalySys Consulting, in Alamo, Calif., which specializes in consulting for the development of medical and analytical instruments. Before founding AnalySys Consulting, he was systems engineering manager at Siemens Ultrasound Inc. from 1986 to 1992. Before going to Siemens, he was a hardware design engineer and project leader for the Instrument Division of Varian Associates in Walnut Creek, Calif., for six years.

EEs' tools & toys

IBM offers bare-board tester to outsiders

There is an up side to everything. In the case of IBM Corp., the good news is that beleaguered finances have persuaded the computer giant to sell some products and services it had been reserving for internal use. One of the niftier is a go/no-go electrical tester for finding flaws in printed wiring.

Called Latest (for LAtent-open TEST), the instrument superimposes an ac signal on a larger dc level that it drives through the traces under test. By analyzing the distortion induced in the ac signal, Latest can spot not only open circuits, but incipient opens as well. What is more, it can distinguish among the

To check out a suspect trace, the operator first positions a probe at each of its extremities, then gets the tester to drive a dc current through it. By analyzing the distortions induced in an ac signal riding on the dc level, the instrument can detect and distinguish among a large number of latent failure types.

types of imminent failures—neckdowns, dishdowns, mouse bites, hairline cracks, barrel cracks, voids, reductions, and separations—that jeopardize circuit reliability.

The tester even has a talent for finding process-related defects, which are usually hard to locate without costly and time-consuming destructive tests. According to IBM, the company has used Latest for nearly 10 years to find defects that could not be found with time-domain reflectometry, four-point resistance measurements, and other expensive techniques.

Latest is offered in two forms: one for printed-circuit boards and the other for ceramic substrates, as used in multichip modules, for example. Either model may be used as a manually operated stand-alone unit or as part of an automated tester in conjunction with a robot. Price of the circuit-board model is US $48 000, with delivery in four to six weeks; price of the other model is still being set. *Contact: Irv Memis, IBM Endicott Electronic Packaging, 1701 North St., Endicott, NY 13760; 800-934-0104; fax, 607-757-1022; or* **circle 110.**

EDUCATION

Visualizing convolution

Compact though the integral equation is for convolution, most students find it difficult to visualize the operation in order to gain an intuitive understanding of its application. The bridge to appreciating how the flip-slide-multiply-integrate sequence works involves animation, something not easily achieved in a book or on a chalk board.

Enter the software package, P.C. Convolution. A student easily enters a variety of functions, including Dirac Delta functions, and then is stepped through the convolution process. Unlike packages that simply perform convolution and show the result, P.C. Convolution is a teaching tool that studiously displays the intermediate products of the calculation. The software will work with both continuous and discrete time signals and performs convolution, correlation, and circular convolution.

P.C. Convolution is a simple, menu-driven package. Most students spend less than 5 minutes learning how to use it and never need to read the users' manual. It executes on most IBM personal computers and equivalents. The program runs under DOS 4.0 (or later) or Windows, and requires an 80286 processor or better, 640 kB of RAM, and an EGA-compatible graphics card. A math coprocessor is recommended but not required.

The program is distributed free of charge to college and university instructors. A demonstration version may be obtained over the Internet via anonymous ftp from franklin@ee.umr.edu (IP# 131.151.4.6, file name /pub/pcc). A fully operational version is also available. *Contact: K. Kosbar, 117 EE Building, University of Missouri-Rolla, Rolla, MO 65401; 314-341-4894; e-mail, kk@ee.umr.edu; or* **circle 111.**

A Pentium design guide

Anxious to apply the Pentium microprocessor from Intel Corp. to one of your systems? Then consider purchasing a new third-party design handbook, *Pentium processor system architecture* (MindShare Press, Richardson, Texas, 1993).

The book's authors, Don Anderson and Tom Shanley, are instructors who claim to have trained "thousands" of engineers and technicians on PC system architectures at companies like IBM, Compaq, Dell, and, yes, Intel. In fact, the pair conducts the primary technical training courses on the Pentium itself at these companies.

The 306-page book promises to guide readers concisely one step at a time through the microprocessor's architecture, "unlike mammoth data books that may be confusing and uninformative." And according to Michael Slater, publisher of the industry newsletter *Microprocessor Report,* the book "is more readable and offers more perspective than Intel's documentation." At only $29.95, the book sounds worth a shot.

The book is sold at technical bookstores or it may be ordered by mail. *Contact: Order Desk, Computer Literacy Bookshops, 2590 North First St., San Jose, CA 95131; 408-435-0744; fax, 408-435-1823; e-mail, info@clbooks.com; or* **circle 112.**

INSTRUMENTATION

A (fairly) inexpensive digital scope

Priced at $4950, the TDS 410 digital storage oscilloscope from Tektronix Inc. is not a low-cost instrument. But considering its sampling rate of 100 megasamples per second and its ability to store 15 000 samples from each of its two inputs, it cannot be called expensive either. The 410 has a bandwidth of 150 MHz and a sensitivity of 1 mV per division. Its vertical channels are accurate to

The TDS 410 digital sampling oscilloscope from Tektronix Inc. features a bandwidth of 150 MHz, a sampling rate of 100 megasamples/s, and a price tag of $4950. Using an optional package, this scope has calculated a fast Fourier transform [bottom trace] from a stored waveform [top trace].

within 1.5 percent of full scale.

The latest member of the company's TDS 400 series, the 410 boasts many of the same features as the other family members. It has a repertoire of 25 automatic measurements, including rise time, fall time, duty cycle, mean

value, root-mean-square value, burst width, and frequency. It stores up to 10 setups in nonvolatile memory so that complex and/or frequently needed measurements may be made expeditiously. And it lets the user create pass/fail templates for conformance verification in manufacturing test.

For an additional $995, users may add an optional fast Fourier transform (FFT) math pack, which includes integration and differentiation as well as FFTs [photo]. Other options include video triggering, interfaces and formats for most printers and plotters, and direct download to popular desktop publishing programs.

The TDS 410 has a delivery time of approximately four weeks. *Contact: Tektronix Inc., Test and Measurement Group, Box 1520, Pittsfield, MA 01202; 800-426-2200, ext. 282; or* **circle 113.**

A cost-conscious electrometer

Mandatory for many applications in optics, materials science, and other areas of physics, electrometers—if not too expensive—may also be attractive to test engineers evaluating high-impedance components. Their appeal is as an alternative to digital multimeters for making low-current measurements. One electrometer that seems to meet that cost criterion is the $2995 Model 6512 from Keithley Instruments Inc. The 4-1/2-digit instrument has just 5 fA (5×10^{-15} A) of bias current, less than 1 mV of burden voltage, and an input impedance in excess of 200 TΩ (200×10^{12} Ω). It measures current from <2 fA to 20 mA, resistance from 100 mΩ to 200 GΩ, voltage from 10 μV to 200 V, and charge from 10 fC to 20 nC.

For current measurements, the meter uses a feedback ammeter design, which isolates the very large current-sampling resistor from the input cable capacitance, thus avoiding the problem of long settling times caused by the long R-C time constant of the sampling resistance and the cable capacitances. For voltage and resistance measurements, it achieves a similar result by allowing users to drive the inner shield of its triaxial input cable to the guard voltage.

In addition to front-panel push buttons, the 6512 can be controlled via an IEEE-488 interface bus. The bus handles all functions, including zero-correction (for canceling internal offsets) and suppression (for making measurements with respect to a selected baseline). *Contact: Keithley Instruments Inc., 28775 Aurora Rd., Cleveland, OH 44139; 800-552-1115; fax, 800-936-3300; or* **circle 114.**

Pay-per-use board test

The trouble with top-end board testers is that their cost is hard to justify unless they are in more or less constant use. Since not every potential user can keep one busy all the time, Hewlett-Packard Co. has ingeniously invented a pay-per-use board-test system.

The HP 3070 is a fully configured combinational test system priced on a par with an HP 3072 unpowered tester. (The actual price is a function of node count; a 1300-node system goes for $132 000.)

When the tester is used for unpowered opens testing, the customer pays no additional fee to H-P. If in-circuit or combinational testing is required, a test credit button similar to a subway token card is inserted into the system, which then debits pre-purchased test credits at whatever rates apply to the tests performed. Users thus have all the test capability they may need always to hand, but pay for it only when they use it.

"This system is the ultimate in asset utilization," said David W. Webb, business analyst and pay-per-use product manager with H-P's Manufacturing Test Division in Loveland, Colo. "The risk associated with underutilization of the tester is virtually eliminated."

The system may be upgraded at any time to an advanced Model HP 3073 or 3075. All pay-per-use hardware and 50 percent of all test credit buttons count as equity toward an upgrade. The H-P 3070 pay-per-use sys-

Tools & toys

tem has a delivery time of 8–12 weeks. *Contact: Hewlett-Packard Co., Direct Marketing Organization, Box 58059, MS51 l-SJ, Santa Clara, CA 95051-8059; or* **circle 115.**

GENERAL INTEREST

Free electronic newsletter

HOTT, which stands for Hot Off The Tree, is a monthly electronic newsletter that will cover the latest technological advances in computers, communications, and electronics. It commences publication at just about the same time that this issue of *Spectrum* appears.

According to its publisher, David Scott Lewis, editor-in-chief and book and video review editor of *IEEE Engineering Management Review,* each issue will provide article summaries on new and emerging technologies. Among the topics to be covered are virtual reality, neural networks, personal digital assistants, graphical user interfaces, intelligent agents, ubiquitous computing, genetic and evolutionary programming, wireless networks, smart cards, video phones, set-top boxes, nanotechnology, and massively parallel processing.

Lewis plans for HOTT to provide summaries from a large number of sources, including many major world newspapers and magazines, trade publications, and research journals, including *all* publications of the IEEE Computer and Communications societies.

So how do you sign up for the service? Just send a subscription request to listserv@ucsd.edu. Leave the "subject" line blank. In the body of message input: SUBSCRIBE HOTT-LIST. Do *not* include first or last names following "SUBSCRIBE HOTT-LIST." *Contact: David Scott Lewis, Box 18438, Irvine, CA 92713-8438; 714-662-7037; e-mail: d.s.lewis@ieee.org.*

Putting graphics back in books

As every college student is only too well aware, textbook prices are climbing out of sight. Trade books, too, are feeling the economic pinch, with the result that excellent graphics of various types are routinely omitted from books for economy's sake.

Aware of these trends, and hoping to find a way of countering them, Edward J. Sylvester of the Walter Cronkite School of Journalism and Telecommunication at Arizona State University (ASU) is putting his book, *The Healing Blade: A Tale of Neurosurgery,* on the Internet, whence interested readers may download it at no cost. Published a year ago by Simon & Schuster, the book looks at the human brain through the eyes of neurosurgeons and their patients.

Right now, the prologue, opening chapter, and several graphics files are available, but the real purpose of the exercise, according to Sylvester, is to explore "...how graphics might be made available at little cost for future book buyers...." He hopes to have a cross section of interested parties attempt to download, view, and print personal copies of the graphics as he uploads them.

Readers who use Gopher simply need to locate the ASU Gopher within the Arizona gopher. Once there, they would go to Campus Wide Information Services, then to Journalism, then to Healing Blade. The README file gives information on downloading. Alternatively, access may be gained via Anonymous FTP from info.asu.edu/pub/cwis/journalism/healing_blade.

Sylvester requests that people who have tried to download and read his files report their success (or problems) to him. *Contact: Edward Sylvester, School of Journalism, Arizona State University, Box 871305, Tempe, AZ 85287-1305; America On Line, ESylvester; CompuServe, 71552,3620; Internet, Edward.Sylvester@ASU.Edu.*

COORDINATOR: Michael J. Riezenman
CONSULTANT: Paul A.T. Wolfgang, Boeing Defense & Space Group

…ices. *Tomizawa, Kazutaka,* …Norwood, Mass., 1993, 341 pp.,

…n to Discrete Mathematics, …Specification, and Z, 2nd edi- …, Oxford University Press, …, 286 pp., $29.95.

…f Distributed Software Con-… *Shatz, Sol M.*, Macmillan, …, 209 pp., $58.

…puter Fraud. *Stern, Dana L.*, …New York, 1993, 294 pp.,

…bility with fmake. *DuBois,* … & Associates, Sebastopol, … pp., $27.95.

…uter Systems: Videotex and …*r, Antone F.*, Plenum Press, … 433 pp., $69.50.

…A Computer Laboratory Text-book. *Mersereau, Russell M.*, and *Smith, Mark J.T.*, John Wiley & Sons, New York, 1994, 224 pp., $37.95.

…Mass., 1993, 195 pp., $59.

Introduction to Scanning Tunneling Microscopy. *Chen, C. Julian,* Oxford University Press, New York, 1993, 412 pp., $65.

Digital and Analog Communication Systems, 4th edition. *Couch, Leon W. II,* Macmillan, New York, 1993, 827 pp., $67.

Numerical Simulation of Submicron Semi-

Microsoft MS-DOS Programmer's Reference,

(Continued on p. 68D)

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Aware of these trends, and hoping to find a way of countering them, Edward J. Sylvester of the Walter Cronkite School of Journalism and Telecommunication at Arizona State University (ASU) is putting his book, *The Healing Blade: A Tale of Neurosurgery*, on the Internet, whence interested readers may download it at no cost. Published a year ago by Simon & Schuster, the book looks at the human brain through the eyes of neurosurgeons and their patients.

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COORDINATOR: Michael J. Riezenman
CONSULTANT: Paul A.T. Wolfgang, Boeing Defense & Space Group

Recent books

Using C in Software Design. *Leach, Ronald,* Academic Press, Cambridge, Mass., 1993, 402 pp., $39.95.

Optical Transmission for the Subscriber Loop. *Kashima, Norio,* Artech Press, Norwood, Mass., 1993, 314 pp., $75.

Ultraclean Technology Handbook, Vol. 1: Ultrapure Water. *Ohmi, Tadahiro,* Marcel Dekker, New York, 1993, 928 pp., $195.

Electronic Devices and Circuits Using MICRO-CAP II. *Berube, R.H.,* Macmillan, New York, 1993, 278 pp., $27.

The QFD Book: The Team Approach to Solving Problems and Satisfying Customers Through Quality Function Deployment. *Guint, Lawrence R.,* and *Praizler, Nancy C.,* Amacom, New York, 1993, 124 pp., $26.95.

Global High-Tech Marketing: An Introduction for Technical Managers and Engineers. *Kadish, Jules E.,* Artech Press, Norwood, Mass., 1993, 195 pp., $59.

Introduction to Scanning Tunneling Microscopy. *Chen, C. Julian,* Oxford University Press, New York, 1993, 412 pp., $65.

Writing Disaster Recovery Plans for Telecommunications Networks and LANs. *Wrobel, Leo A.,* Artech House, Norwood, Mass., 1993, 138 pp., $55.

Logic Design Theory. *Biswas, Nripendra N.,* Prentice Hall, Englewood Cliffs, N.J., 1993, 306 pp., $59.

Virtual Reality: Applications and Explorations. *Wexelblat, Alan,* Academic Press, Cambridge, Mass., 1993, 245 pp., $39.95.

Fuzzy Logic and Control. Eds. *Jamshidi, Mohammad, et al.,* Prentice Hall, Englewood Cliffs, N.J., 1993, 397 pp., $72.

Electronic Packaging, Microelectronics, and Interconnection Dictionary. *Harper, Charles A.,* and *Miller, Martin B.,* McGraw-Hill, New York, 1993, 235 pp., $39.50.

Robotics and Remote Systems for Hazardous Environments. Eds. *Jamshidi, Mohammad,* and *Eicker, Patrick J.,* Prentice Hall, Englewood Cliffs, N.J., 1993, 229 pp., $72.

Digital and Analog Communication Systems, 4th edition. *Couch, Leon W. II,* Macmillan, New York, 1993, 827 pp., $67.

Numerical Simulation of Submicron Semiconductor Devices. *Tomizawa, Kazutaka,* Artech House, Norwood, Mass., 1993, 341 pp., $94.

An Introduction to Discrete Mathematics, Formal System Specification, and Z, 2nd edition. *Ince, D.C.,* Oxford University Press, New York, 1993, 286 pp., $29.95.

Development of Distributed Software Concepts and Tools. *Shatz, Sol M.,* Macmillan, New York, 1993, 209 pp., $58.

Preventing Computer Fraud. *Stern, Dana L.,* McGraw-Hill, New York, 1993, 294 pp., $39.95.

Software Portability with Imake. *DuBois, Paul,* O'Reilly & Associates, Sebastopol, Calif., 1993, 365 pp., $27.95.

Interactive Computer Systems: Videotex and Multimedia. *Alber, Antone F.,* Plenum Press, New York, 1993, 433 pp., $69.50.

Digital Filtering: A Computer Laboratory Textbook. *Mersereau, Russell M.,* and *Smith, Mark J.T.,* John Wiley & Sons, New York, 1994, 224 pp., $37.95.

Microsoft MS-DOS Programmer's Reference,

(Continued on p. 68D)

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Recent books

(Continued from p. 68A)

2nd edition. *Microsoft Corp.*, Microsoft Press, Redmond, Wash., 1993, 528 pp., $27.95.

Higher-Order Spectra Analysis: A Nonlinear Signal Processing Framework. *Nikias, C.L.*, and *Petropulu, Athina P.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 537 pp., $62.

Stereo Computer Graphics and Other True 3D Technologies. Ed. *McAllister, David F.*, Princeton University Press, Princeton, N.J., 1993, 267 pp., $75.

Power Electronics: Circuits, Devices, and Applications, 2nd edition. *Rashid, Muhammad H.*, Prentice Hall, Englewood Cliffs, N.J., 1988, 702 pp., $56.

NetView: A Professional's Guide to SNA Network Management. *Trindell, Larry D.*, McGraw-Hill, New York, 1993, 632 pp., $55.

User Interface Software. *Bass, Len*, John Wiley & Sons, New York, 1993, 201 pp., $38.95.

Electron Beam Testing Technology. Ed. *Thong, John T.L.*, Plenum Press, New York, 1993, 462 pp., $89.50.

Random Signals and Systems. *Picinbono, Bernard*, Prentice Hall, Englewood Cliffs, N.J., 1993, 591 pp., $60.

The Elements of Technical Writing. *Blake, Gary*, and *Bly, Robert W.*, Macmillan, New York, 1993, 174 pp., $18.

Running Visual Basic for Windows, 2nd edition. *Nelson, Ross*, Microsoft Press, Redmond, Wash., 1993, 352 pp., $22.95.

Compound and Josephson High-Speed Devices. Eds. *Misugi, Takahiko*, and *Shibatomi, Akihiro*, Plenum Press, New York, 1993, 306 pp., $69.50.

Choosing and using 4 bit microcontrollers. *McDowell, Philip*, Marcel Dekker, New York, 1993, 246 pp., $69.95.

Principles of Communications Satellites. *Gordon, Gary D.*, and *Morgan, Walter L.*, John Wiley & Sons, New York, 1993, 533 pp., $69.95.

Review of Progress in Quantitative Nondestructive Evaluation, 12A and 12B. Eds. *Thompson, Donald O.*, and *Chimenti, Dale E.*, Plenum Press, New York, 1993, two volumes: 1168 pp. (12A) and 2431 pp. (12B), $345 each.

Electro-Magnetic Interference: Reduction in Electronic Systems. *Mills, Jeffrey P.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 258 pp., $47.

Quick Reference Guide: WordPerfect 6.0 IBM PC. *Miller, Deborah J.*, Dictation Disc, New York, 1993, 246 pp., $8.95.

The EMF Controversy & Reducing Exposure from Magnetic Fields: ELF Magnetic Field Reduction from Power Utilities to Home Wiring. *White, Don, et al.*, Interference Control Technologies, Gainesville, Va., 1993, 181 pp., $95.

OSI Protocol Conformance Testing: IS 9646 Explained. *Knightson, Keith G.*, McGraw-Hill, New York, 1993, 238 pp., $43.

Multiple Access Communications: Foundations for Emerging Technologies. Ed. *Abramson, Norman*, IEEE Press, Piscataway, N.J., 1993, 519 pp., $56 (member price), $69.95 (list price).

Quick Reference Guide: MS-DOS 6. *Schwartz, Karl*, Dictation Disc, New York, 1993, 227 pp., $8.95.

Inside Visual C++: New Ways to Program for Windows Using the Advanced Tools in

Microsoft Visual C++. *Kruglinski, David J.*, Microsoft Press, Redmond, Wash., 1993, 632 pp., $39.95.

The Fractal Company: A Revolution in Corporate Culture. *Warnecke, H.J.*, Springer-Verlag, New York, 1993, 228 pp., $39.

CICS: Capacity Planning and Performance Management. *Keller, Ted C.*, McGraw-Hill, New York, 1993, 407 pp., $40.

Contemporary Linear Systems Using MatLab. *Strum, Robert D.*, and *Kirk, Donald E.*, PWS Publishing, Boston, 1994, 684 pp., $34.50.

McGraw-Hill's Handbook of Electrical Construction Calculations. *McPartland, Joseph F., et al.*, McGraw-Hill, New York, 1993, 454 pp., $49.50.

Jargon: An Informal Dictionary of Computer Terms. *Williams, Robin, et al.*, Peachpit Press, Berkeley, Calif., 1993, 676 pp., $22.

Distributed Computing Environments. Eds. *Cerutti, Daniel*, and *Pierson, Donna*, McGraw-Hill, New York, 1993, 398 pp., $50.

FDOI: A High Speed Network. *Shah, Amit*, and *Ramakrishnan, G.*, Prentice Hall, Englewood Cliffs, N.J., 1994, 229 pp., $55.

Surface Emitting Semiconductor Lasers and Arrays. Eds. *Evans, Gary A.*, and *Hammer, Jacob M.*, Academic Press, San Diego, Calif., 1993, 505 pp., $110.

Spice for Power Electronics and Electric Power. *Rashid, Muhammad H.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 394 pp., $29.

Electric Protective Devices. *Denno, Khalil*, McGraw-Hill, New York, 1994, 295 pp., $60.

A Short History of Technology: From Ancient Times to A.D. 1900. *Derry, T.K.*, and *Williams, Trevor I.*, Dover Publications, Mineola, N.Y., 1993, 782 pp., $16.95.

Journeyman's Guide to the National Electrical Code 1993. *Gotshaw, F. Marco*, Prentice Hall, Englewood Cliffs, N.J., 1993, 559 pp., $46.

The Children's Machine: Rethinking School in the Age of the Computer. *Papert, Seymour*, Harper Collins, New York, 1993, 241 pp., $22.50.

Phantom Risk: Scientific Inference and the Law. Eds. *Foster, Kenneth R., et al.*, MIT Press, Cambridge, Mass., 1993, 457 pp., $39.95.

Inside OLE 2. *Brockshmidt, K.*, Microsoft Press, New York, 1994, 977 pp., $49.95.

Optimal Control of Stochastic Systems. *Bagchi, A.*, Prentice Hall, New York, 1993, 335 pp., $64.

The New Handbook for Electricians. *Clifford, M.*, and *Clifford, J.R.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 358 pp., $44.

Pulse Width Modulated (PWM) Power Supplies. *Quercioli, V.*, Elsevier Science, New York, 1993, 310 pp., $160.

Digital Woes: Why We Should Not Depend on Software. *Wiener, Lauren Ruth*, Addison-Wesley, Reading, Mass., 1993, 256 pp., $19.95.

Matched Field Processing for Underwater Acoustics. *Tolstoy, Alexandra*, World Scientific, River Edge, N.J., 1993, 212 pp., $58.

Modern Electronic Communication, 4th edition. *Miller, Gary M.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 626 pp., $60.

Social Dimensions of Systems Engineering: People, Processes, Policies and Software Development. Ed. *Quintas, Paul*, Ellis Horwood, Hemel Hempstead, Herts., UK., a division of Simon Schuster, 1993 (paperback).

Calendar

(Continued from p. 14)

APRIL

Second International Conference on Ultra-Wideband, Short-Pulse Electromagnetics (MTT); April 5–7; Weber Research Institute, Polytechnic University, Brooklyn, N.Y.; Lawrence Carin, Polytechnic University, 333 Jay St.. Brooklyn, NY; 718-260-3600; fax, 718-260-3136.

Southeastcon '94 (Region 3, et al.); April 10–13; Hyatt Regency Hotel, Miami, Fla.; Osama A. Mohammed, Department of Electrical Engineering, Florida International University, University Park Campus, Miami, FL 33199; 305-348-3040; fax, 305-348-3707.

Workshop on FPGAs for Custom Computing Machines (C); April 10–13; Sheraton Inn at Napa Valley, California; Kenneth L. Pocek, Intel Corp., MS RNG-18, 2200 Mission College Rd., Box 58119, Santa Clara, CA 95052; 408-765-6705; 408-765-5165; e-mail, kpocek@sc.intel.com.

Transmission and Distributed Conference and Exhibition (PE, Chicago Section); April 10–15; McCormick Place, Chicago; John J. Viera, Commonwealth Edison, Box 767, Chicago, IL 60690; 312-294-3333.

International Reliability Physics Symposium (ED, R); April 11–14; Fairmont Hotel, San Jose, Calif.; Richard Blish, Intel Corp., 5000 W. Chandler Blvd., Chandler, AZ 85226; 602-554-4127; fax, 602-554-6098.

Third Maghrebian Conference on Software Engineering and Artificial Intelligence (C); April 11–14; Hyatt Regency Hotel, Rabat-Agdal, Morocco; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Position, Location and Navigation Symposium—Plans '94 (AES); April 11–15; Bally's Hotel, Las Vegas, Nev.; Michael Hadfield, 12449 84th Way N., Largo, FL 34643; 813-531-5715.

12th European Photovoltaic Solar Energy Conference and Exhibition—PSEC (ED); April 11–15; RAI Congress Centre Amsterdam, the Netherlands; Heinz Ehmann/Andrea Zepf, WIP - Munich, Sylverstinstr. 2, D-81369, Munich, Germany; (49+89) 720 12 32,; fax, (49+89) 720 12 91.

13th Annual International Phoenix Conference on Computers and Communications (C, COM); April 12–15; YWCA, U.S. Leadership Development Center, Phoenix, Ariz.; Lana Ruch, American Express, 10030 N. 25th Ave., Phoenix, AZ 85021; 602-548-6025; fax, 602-548-6060.

Third International Conference and Exhibition on Multichip Modules (CPMT); April 13–15; Currigan Exhibition Hall, Denver, Colo.; Richard Breck, ISHM, 1850 Centennial Park Dr., Suite 105, Reston, VA 22091; 800-535-4746, ext. 230; fax, 703-758-1066.

International Symposium on Speech, Image Processing and Neural Networks (SP, Hong Kong Section); April 14–16; Hong Kong Convention and Exhibition Centre; Chorkin Chan, Department of CS, University of Hong Kong, Hong Kong; (8+52) 859 7075; fax, (8+52) 559 8447; e-mail, cchan@csd.hku.hk.

21st International Symposium on Computer Architecture (C); April 18–21; The Westin Hotel, Chicago; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

International Conference on Require-

(Continued on p. 76)

PRODUCT PROFILES

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Program notes

Basic re-re-re-renovation

Programming in Basic is like living in a house under continuous renovation. During its three decades, Basic has changed its floor plan at least four times. Built as a teaching language, it was expanded to hobbyist status, and then enlarged into a full-featured procedural language. In its latest remodeling, it is struggling to find a role in the world of graphical operating environments.

Developing a Basic compiler for Windows is much harder than developing one for older operating systems like DOS, Unix, or VMS. Basic is designed to execute one procedure (a function or subroutine) after another until the program is finished. Windows is a message-driven operating environment with messages being generated by external events, by changes in the operating system's status, and even by changes in the status of other programs.

After receiving a message, the operating system and other programs act on it and then wait for another message. To facilitate this process, Windows programming languages must simplify the writing of programs that respond to messages from hardware, the operating system, and other programs.

Compiler developers are taking two approaches to Basic for Windows. Some use only the Windows message-driven programming technique. For instance, Microsoft Corp. has chosen to develop the easy-to-use Visual Basic. Yet even with this compiler's help, the best procedural programmers will at first find writing for Windows difficult, because they must switch mental gears from procedure- to message-driven techniques.

The second approach mixes procedural and message-driven programming techniques. For example, Computer Associates (CA) has designed a handy compiler that is partly message-driven but mostly procedural. Even novice procedural programmers will be able to write code for the CA-Realizer, but they must rely on this compiler to supply many tools that a Visual Basic programmer would create. Non-Windows programmers may use CA-Realizer to develop occasional programs, though they will learn little about Windows. They can use it, too, to create programs for OS/2.

Both Microsoft and CA are also pushing their versions, or dialects, of Basic as Windows macro languages. Microsoft is converting all its Windows applications to a subset of Visual Basic, called Visual Basic Application Edition, but the company has no plans to make its macro language tools available to other programmers. CA, on the other hand, is offering a subset of CA-Realizer, called CA-Cable, as a macro language that developers of both Windows and OS/2 programs can license; they may find it a convenient shortcut for getting programs with macro languages to market. *Contacts: Microsoft Corp., 1 Microsoft Way, Redmond, WA 98052-6399; 206-882-8080; or* **circle 100***; and Computer Associates International Inc., 1 Computer Associates Plaza, Islandia, NY 11788; 800-225-5224; or* **circle 101**.

Could it be...Satan?

Education and the widespread use of detection software have made traditional computer viruses, like Stoned and Michelangelo, a mere

nuisance. But now a new generation may be much more, well, virulent.

Take the Satan Bug, a stealth virus that is network aware. As a stealth virus, it can defeat the two traditional methods for avoiding viruses: string and pattern detection. In string detection, anti-virus programs search files for common message strings used by viruses—like "Cookie" or "Get stoned". Programs using pattern detection are made to scan files for bit patterns associated with common viruses.

Stealth viruses avoid both detection methods by encrypting all message strings and by slightly modifying every new copy of the virus; the latter characteristic is called polymorphism ["Threats and countermeasures," *IEEE Spectrum*, August 1992, pp. 21–28].

Obviously, this type of virus poses a serious threat, requiring more effort to detect than the garden-variety virus. What can be done to restrain such an antagonist? While programmers may be unable to prevent what they write from being infected, they can still indicate whether or not an infection has occurred.

A shareware program that generates the necessary information is McAffee & Associates' Validate. Authors and publishers of software may use Validate's two discrete methods to calculate cyclic redundancy checks (CRCs) for their offerings, and then list the valid numbers in a README.TXT file shipped with the software.

When a supplier protects a program in this manner, its users can also employ Validate to generate CRCs for the copy currently on their systems. Comparing the numbers the CRCs produce with those from the README.TXT file can show whether the copy has been altered: any difference means a problem.

To learn more about computer viruses, read Patricia Hoffman's "VSUM," an IBM-compatible PC hypertext document that describes over 1000 viruses in detail. A copy may be down-loaded for brief evaluation from the McAffee & Associates' bulletin-board system. *Contact: McAffee & Associates, 4423 Cheeney St., Santa Clara, CA 95054; 408-988-3832 (bulletin-board system: 408-988-4004); or* **circle 102***; and Patricia M. Hoffman, 3333 Bowers Ave., Suite 130, Santa Clara, CA 95054; 408-988-3773; or* **circle 103.**

Part-time programming shortcut

Software vendors are now pushing a two-layer strategy that divides the programming world into two hemispheres: module (object) suppliers, and solution (application) builders. The former are hard-core programmers who use sophisticated tools to create linkable modules or objects. The latter are the part-timers who work with uncomplicated software tools to build an application outline by linking modules or objects.

With their support of dynamic link libraries (DLLs), both Windows and OS/2 are well suited to this division of labor. A component supplier can produce DLLs, which must be written in a sophisticated programming language like C++. An application builder can use the DLLs as part of a new application created by an easy-to-use language without having to worry about what is in them.

A good example of how this approach can work is Crystal Computer Services' Crystal Reports 2.0, a Windows-based report writer that contains a DLL. Using Visual Basic or Turbo Pascal, application builders may call on any or all of the functions in the report writer's Report Engine DLL when they want to add professional-looking reports to applications. *Contact: Crystal Computer Services, 1050 W. Pender St., Suite 2200, Vancouver, BC, Canada V6E 3S; 604-681-2934; or* **circle 104.**

CONTRIBUTOR: John R. Hines is a silicon sensor engineer at Honeywell Inc.'s Micro Switch Division, Richardson, Texas.
CONSULTANT: Bruce Mather, Southwest Research Institute.

Calendar

(Continued from p. 71)

ments Engineering (C); April 18–22; Broadmoor Hotel, Colorado Springs, Colo.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

International Symposium on Theoretical Aspects of Computer Software (C); April 19–21; Tohoku University, Sendai, Japan; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

International Conference on Acoustics, Speech and Signal Processing (SP); April 19–22; Adelaide Convention Center, South Australia; Phil Plevin, Plevin & Associates Pty., Box 54, Burnside 5066, South Australia; (61+8) 379 8222; fax, (61+8) 379 8177.

Southwest Symposium on Image Analysis and Interpretation (SP, Dallas Section); April 21–22; Grand Kempinski Hotel, Dallas; Alireza Khotanzad, Southern Methodist University; 214-768-3101; fax, 214-768-3883; e-mail, kha@seas,smu.edu; or Nasser Kehtarnavaz, Texas A&M University; 409-845-8371; fax, 409-845-6259; e-mail, kehtar@ee.tamu.edu.

Rural Electric Power Conference (IA); April 24–26; Sheraton Colorado Springs Hotel, Colorado; Donald E. Werner, Omaha Public Power District, 444 South 16th St. Mall, Omaha, NE 68102-2247; 402-636-2585.

International Workshop on Computer-Aided Modeling, Analysis, and Design of Communication Links and Networks—Camad '94 (COM); April 24–27; Princeton Marriott Hotel, New Jersey; Benjamin Melamed, NEC USA Inc., 4 Independence Way, Princeton, NJ 08540; 609-951-2450; fax, 609-951-2499.

ACM Conference on Human Factors in Computer Systems (C); April 24–28; Hynes Convention Center, Boston; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

VLSI Test Symposium (C, Philadelphia Section); April 25–28; Cherry Hill Hyatt Hotel, New Jersey; Prab Varma, CrossCheck Technology, 2833 Junction Ave., San Jose, CA 95134; 408-432-9200; fax, 408-432-0907; e-mail, prab@crosscheck.com.

44th Electronic Components and Technology Conference—ECTC '94 (CHMT); April 30–May 5; Washington Hilton Hotel, D.C.; James Bruorton, Kernet Electronics, Box 5928, Greenville, SC 29606; 803-963-6621; fax, 803-963-6521.

MAY

Custom Integrated Circuits Conference—CICC '94 (ED, SSC); May 1–4; Town & Country Hotel, San Diego, Calif.; Melissa Widerkehr, Widerkehr and Associates, Suite 610, 1545 18th St., N.W., Washington, DC 20036; 202-986-2166; fax, 202-986-1139.

Industrial and Commercial Power Systems Technical Conference—I&CPS (IA, Orange City); May 1–5; Radisson Plaza Hotel, Irvine, Calif.; Farrokh Shokooh, Electrical Engineering Operation Tech. Inc., C.O.A., 17870 Skypark Circle, Suite 102, Irvine, CA 92714; 714-476-8117.

International Conference on Communications—ICC Supercomm '94 (COM); May 1–5; Ernest N. Morial Convention Center, New Orleans, La.; Eddie Sawaya, South Central Bell Telephone Co., 365 Canal St., Room 710, New Orleans, LA 70140; 504-528-2673; fax, 504-528-7170.

International Symposium on Electronics and the Environment (TAB); May 2–4; San Francisco; Conference Registrar, IEEE Technical Activities, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3878; fax, 908-562-1571.

Offshore Technology Conference—OTC '94 (OE); May 2–5; Astrodomain Complex, Houston, Texas; Deborah Wheeler, Box 833868, Richardson, TX 75083-3868; 214-952-9494; fax, 214-952-9435.

Conference on Lasers and Electro-Optics and the International Electronics Conference—CLEO/IQEC (LEO); May 8–13; Anaheim Convention Center, California; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3893; fax, 908-562-1571.

International Conference on Robotics and Automation (RA); May 8–13; San Diego Princess Resort, California; Harry Hayman, Box 3216, Silver Spring, MD 20918; 301-236-5621; fax, 301-236-5621.

Electro '94 (Region 1, et al.); May 10–12; Hynes Convention Center, Boston; Sharon Schifano, Miller Freeman Inc., 13760 Noel Rd., Suite 500, Dallas, TX 75240; 800-527-0207; fax, 214-419-7915.

Instrumentation and Measurement Technology Conference—IMTC '94 (IM); May 10–12; Grand Hotel Hamamatsu, Japan; Robert Myers, Myers/Smith Inc., 3685 Motor Ave., Suite 240, Los Angeles, CA 90034-5750; 310-287-1463; fax, 310-287-1851.

International Workshop on Networked Reality in Telecommunication (COM); May 13–14; NTT Media Laboratory, Tokyo; Yoshinobu Tonomura, 1-2356, Take, Yokosuka, Kanagawa 238-03, Japan; (81+468) 59 3112; fax, (81+468) 59 2829.

International Conference on Computer Languages—ICCL '94 (C); May 16–19; University Paul Sabatier, Toulouse, France; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Microwave and Millimeter-Wave Monolithic Circuits Symposium (ED); May 23–24; San Diego Convention Center, California; Richard B. Gold, Pacific Monolithics, 245 Santa Ana Court, Sunnyvale, CA 94086-4512; 408-732-8000; fax, 408-732-3413.

Intelligent Networks Workshop—IN '94 (COM); May 24–26; Penta Hotel, Heidelberg, Germany; John Visser, Bell Northern Research, Box 3511, Station C, Ottawa, ON, KiY 4H7, Canada; 613-763-7028; fax, 613-763-3585.

International Microwave Symposium—MTT '94 (MTT); May 24–26; San Diego Convention Center, California; Mario Maury, 8610 Helms Ave., Cucamonga, CA 91730; 714-987-4715.

International Symposium on Atomic Layer Epitaxy and Related Surface Processes (ED); May 25–27; Sendai Memorial Hall, Miyagi Prefecture, Japan; A. Koukitu, Secretary, ALE-3, Faculty of Technology, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184, Japan; (81+423) 81 4221, ext. 336; fax, (81+ 423) 86 3002.

International Symposium on Industrial Electronics—ISIE '94 (IE); May 25–27; Catholic University of Chile, Santiago; Juan R. Pimentel, Universidad de Politecnica de Madrid, Disam, Jose Gutierrez Abascal 2, 28006 Madrid, Spain; (34+1) 561 6989; fax, (34+1) 564 2961.

IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 80055; 908-562-3878; submit conferences for listing to: Ramona Foster, *IEEE Spectrum*, 345 E. 47th St., New York, NY 10017; 212-705-7305.

For additional information on hotels, conference centers, and travel services, see the Reader Service Card.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

The following listings of interest to IEEE members have been placed by educational, goverment, and industrial organizations as well as by individuals seeking positions. To respond, apply in writing to the address given or to the box number listed in care of *Spectrum* Magazine, Classified Employment Opportunities Department, 345 E. 47th St., New York, N.Y. 10017.

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IEEE encourages employers to offer salaries that are competitive, but occasionally a saslary may be offered that is significantly below currently acceptable levels. In such cases the reader may wish to inquire of the employer whether extenuating circumstances apply.

Academic positions open

Assistant Professor of Electrical Engineering. Applications are being accepted for a tenure-track position in the Department of EECS at the University of Wisconsin-Milwaukee (UWM). Departmental primary needs are in the areas of applied electromagnetics, including remote sensing, communications and opto-electronics, although outstanding candidates in other EE areas may be considered. Applicants must have a Ph.D. in electrical engineering or a closely related field. In addition to a strong commitment to teaching, the candidate for this position is also expected to build a strong research program, which can be integrated into the existing programs of the department. Submit curriculum vitae, bibliography and a list of (3) references to: Dr. David Yu, Co-Chair for Electrical Engineering, Department of EECS, UWM, P.O. Box 784, Milwaukee, WI 53201. The deadline for application is March 31, 1994. The University is an Affirmative Action/Equal Opportunity Employer, women and minorities are strongly encouraged to apply. The names of those applicants who have not requested that their identities be withheld and the names of all finalists will be released on request.

Carnegie Mellon University. The department of Electrical and Computer Engineering at Carnegie Mellon University invites applications for a tenure track position at the Assistant Professor level. We are seeking highly qualified candidates who are committed to a career in research and teaching. We are especially interested in a candidate with a strong theoretical and experimental background in control theory and its applications in one or more areas including, but not limited to: intelligent sensors and actuators, intelligent structures, micromechanisms, fault tolerant control systems, human interfaces for real-time control, manufacturing, and robotics. The successful candidate will have the opportunity to form collaborations with one or more active research groups both within and outside the department. The department has active research programs in magnetic recording, optical computing, CAD, real-time systems, signal processing and telecommunications, robotics and controls, MEMS, and solid state devices. Besides, Carnegie Mellon has several research centers that offer the opportunity for collaboration. These include Engineering Design Research Center (a NSF-ERC), Data Storage Systems Center (a NSF-ERC), The Robotics Institute, SRC-CAD Center, Center for Excellence in Optical Data Processing, and Computing Systems Center. Applicants should have a PhD in Electrical Engineering or a related field. Carnegie Mellon University is an equal opportunity affirmative action employer and welcomes applications from women and minority groups. Applicants should submit a resume, a one page statement of research accomplishments and future plans, and up to three of their most significant conference or journal publications to: Professor Robert M. White, Head, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213.

Texas A&M University. The Electrical Engineering Department expects to have several openings for tenure track faculty at all ranks. Applicants must have a Ph.D degree or completion of all requirements by date of hire. For senior positions, applicants should have a proven record of scholarly contributions, and for junior positions, demonstrated potential for quality research and teaching is necessary. The salary is competitive and commensurate with qualifications and experience. Applicants are sought in the areas of computer engineering, microelectronics, power electronics and signal processing. Applicants should send a complete resume, including names and addresses of three references to Dr. A. D. Patton, Department Head, Electrical Engineering Department, Texas A&M University, College Station, TX 77843-3128. Texas A&M University is an equal opportunity/affirmative action employer and actively seeks the candidacy of women and minorities.

University of Washington. The Department of Electrical Engineering has a tenure-track position, at the Assistant Professor level, for the 1994-95 academic year. The department has an outstanding faculty, a history of interdisciplinary collaboration, and a tradition of excellence. Ten of the current faculty have been awarded the NSF National Young Investigator Award, and one has received an NIH Research Career Development Award. Our research funding has increased more than five fold in the last decade. We are also involved in the NSF ECSEL Coalition to develop innovative new engineering curriculum for undergraduate education. In the summer of 1994, we will break ground on a new 320,000 sq. ft. building to be shared with the Department of Computer Science and Engineering. The department has research focus areas in: Communications, Sensors, Integrated Circuits, Imaging, Robotics, Electromagnetics, Optics, and Energy. Applications are invited from highly qualified, research-oriented candidates with creative teaching skills. Send resume with names of three references to Faculty Search Committee, Department of Electrical Engineering FT-10, University of Washington, Seattle, WA 98195. Applications will be accepted until April 15, 1994, or until the position is filled. The University of Washington is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

The University of Akron: Department of Electrical Engineering invites applications for two tenure-track faculty positions at the assistant or associate professor ranks. Required areas are (1) Power Electronics and Motor Drives (2) Computer Networking and Communications. Applicants must have a doctorate in electrical or computer engineering and will be evaluated based on effective teaching, ability to improve the growing graduate program and potential for initiating funded research. Applications will be reviewed monthly until the positions are filled. Send resume, transcripts and a list of three references to: EE Search, Department of Electrical Engineering, The University of Akron, Akron, OH 44325-3904. The University of Akron is an Equal Education and Employment Institution.

Illinois Institute of Technology seeks candidates for a unique, tenured position as the Motorola Professor of Electrical and Computer Engineering. It is expected that the position will be filled by a senior Associate Professor, a Professor, or an Engineer from industry with commensurate qualifications. Candidates must have an earned doctorate in electrical engineering or a related field, and should have a strong background and expertise in telecommunications. The ability to develop a telecommunications center is critical to the position, as is an established research record, and visibility in a major professional society. The ideal candidate should have a combination of academic and industrial experience, or liaison with both. Applicants should send a detailed curriculum vita to: Chair, Faculty Search Committee, Electrical & Computer Engineering Department, Illinois Institute of Technology, 3301 South Dearborn Street, Chicago, Illinois 60616. Illinois Institute of Technology is an equal opportunity affirmative action employer. M/F/H/V

Illinois Institute of Technology Electrical and Computer Engineering Department seeks candidates for a tenure track position at the assistant professor level in the area of power and control. The starting date is for the Fall semester of 1994. Qualifications include an earned Ph.D. in electrical engineering. Previous teaching experience is preferred. Interested parties should submit a complete resume with the names and addresses of three references to: Chair, Faculty Search Committee, Electrical & Computer Engineering Department, Illinois Institute of Technology, 3301 South Dearborn Street, Chicago, IL 60616-3793. Illinois Institute of Technology is an equal opportunity affirmative action employer. M/F/H/V

Massachusetts Institute of Technology, Department of Mechanical Engineering. The Department of Mechanical Engineering invites the submission of applications for a faculty position in Information Science and Technology to begin in the Fall of 1994. The appointment will be for a tenure track Assistant/Associate Professor. Outstanding senior candidates that strongly fulfill the department's goals may be considered for a tenured position at Associate/Full Professor rank. The successful candidate is expected to conduct research and introduce teaching innovations in the areas of information science and technology. The candidate will contribute to at least one of the following subject areas: product/system design, control systems, fluid and thermal sciences, bioengineering, man-machine systems, applied mechanics, transportation and manufacturing. Applicants must have earned a Doctoral degree in Science or Engineering with experience in engineering systems and information science and technology. In particular, a strong background in multi-disciplinary engineering systems is highly desirable. Interested individuals with applicable industrial experience are encouraged to apply. Applicants should send a curriculum vitae (with citizenship and/or visa status) including a publication list and the names, addresses, and telephone numbers of at least four references. In addition, each applicant must send a one page professional statement describing his/her goals and aspirations at MIT. The statement is important in the selection process. Applications should be sent to the following address, Information Science & Technology Search Chair, Massachusetts Institute of Technology, Department of Mechanical Engineering, Room 3-173, 77 Massachusetts Avenue, Cambridge, Mass 02139. Applications received after April 15, 1994 may not be given full consideration. MIT is an Equal Employment Opportunity/Affirmative Action Employer. Women and members of minority groups are strongly encouraged to apply.

Rice University, Department of Electrical and Computer Engineering, is seeking imaginative and dynamic candidates with an exceptional record of research accomplishments in the area of electronic materials for the Stanley C. Moore Chair in Engineering. The successful candidate is expected to perform an innovative research program in an area of electronic materials and/or devices which transcends traditional boundaries. Of particular interest is research being performed on the nanometer scale, complementing the newly-announced Nanotechnology Initiative at Rice, the Rice Quantum Institute, and the current Physical Electronics group of the ECE Department. The candidate must also have a strong commitment to teaching at both the undergraduate and graduate level. While it is anticipated that an appointment will be made at the senior level, exceptionally well-qualified applications at all levels will be considered. Candidates should send a resume, including names of references and a

research description, to the Chair, ECE Department, Rice University, Houston, TX 77251-1892. Applications should be received by August 1, 1994. Rice University is committed to attracting qualified persons of diverse backgrounds to its faculty, and is an Equal Opportunity/Affirmative Action Employer.

Electrical Engineering. Tenure-track position available Fall 1994 to teach courses in EE and EET, ability to teach physics & math is an advantage. Master's in electrical engineering required. Min 5 yrs. industrial experience & P.E. license desired. 2 yrs. successful teaching experience w/demonstrated ability in field & some teaching experience at college level required. Salary mid-20's, outstanding benefits package. Ocean County College is a public, 2 yr. community college located in the heart of the Jersey Shore, midway between New York City and Atlantic City. Send application/resume, transcripts, and 3 professional letters of reference to Ocean County College, Personnel Dept, PO Box 2001, Toms River, New Jersey, 08754 by 4/15/94. AA/EOE.

Distinguished Professor. The School of Electrical Engineering and Computer Science at Washington State University invites applications and nominations for the position of Distinguished Professor in the general area of analog and mixed analog/digital integrated circuit design, integrated sensor technology development, telecommunications, and/or instrumentation. The endowment for this professorship has been provided by leading manufacturers of electronic circuits and the State of Washington. The individual sought to fill the position must have a proven record of achievement in academia and/or industry. Rank and tenure will be based on experience. The electronics program has traditionally been an important one in the College of Engineering at Washington State University, enjoying the support and respect of many leading industries. The School has established an NSF University/Industry Center for the Design of Analog/Digital Integrated Circuits (CDADIC) with 12 participating industrial companies. The successful applicant will provide technical leadership within the Center and School, and actively promote relationships with industry. In addition, the person filling this position should: 1) Teach courses at both the graduate and undergraduate levels; 2) Establish and carry out a program of funded research in a significant area of electronics; 3) Enhance professional interaction with industry and federal agencies. Letters of nomination and/or applications for this position should be sent to Professor Anjan Bose, Director, School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA 99164-2752; (509) 335-8148. Applications should include a complete professional vita and a list of references. Final screening will begin April 15, 1994 and will continue until the position is filled. WSU is an EO/AA educator and employer. Protected group members are encouraged to apply.

Concordia University, Department of Electrical and Computer Engineering. The Department of Electrical and Computer Engineering at Concordia University invites applications for two tenure-track positions in Computer Engineering at the Assistant Professor level. One of these positions is in the Software Engineering area with emphasis on one or more of the following: Software Architecture and Design Methods; Requirements Engineering; Real-Time Systems. The second position is in the Protocol Engineering area with emphasis on Telecommunications Networking/Software and Formal Methods for Protocol Design and Validation. For both positions, applicants must have a Ph.D. in Electrical/Computer Engineering or Computer Science and a strong commitment to excellence in research and teaching at the undergraduate and graduate levels. Knowledge of French will be an asset. The candidates are expected to possess qualifications essential to register as a Professional Engineer. The Department offers Bachelor's programs in Electrical and Computer Engineering and Master's and Doctoral programs in Electrical engineering. The department currently has 27 full-time faculty members. Faculty research interests in Computer Engineering cover VLSI Systems Design; High Performance Architecture and Computing; Parallel CAD; Communication Network/Systems and Performance Evaluation; Robotics and Signal Processing Algorithms. There are over 175 graduate students of whom approximately 60 are doctoral candidates. For successful applicants opportunities exist for collaborative research with members of the department as well as members in our Computer Science Department. Faculty members of our department are active participants in several inter-university research centers at the provincial and national levels: GRIAO, Inter-University Research Center on High Performance Architecture and VLSI; MICRONET, National Network of Centers of Excellence in Microelectronics Circuits, Systems and Devices; CITR, National Network of Centers of Excellence in Telecommunications Research; IRIS, National Network of Centers of Excellence in Robotics and Intelligent Systems; and CRIM (Centre de Reserche Informatique de Montreal). Montreal is the home of four major universities and of several industries and has emerged as a primary Canadian center for high-tech research. In accordance with Canadian Immigration requirements, priority will be given to citizens and permanent residents of Canada. Concordia University is committed to employment equity and encourages applications from women, aboriginal people, visible minorities and disabled persons. All things being equal, women candidates shall be given priority. Applications will be accepted until the positions are filled. Applicants should send a resume and names of at least three references to: Dr. K. Thulasiraman, Chairperson, Department of Electrical and Computer Engineering, Concordia University, 1455 de Maisonneuve Blvd., West, Montreal, Quebec, H3G 1M8, Canada. Phone: (514) 848-3076. Fax: (514) 848-2802. Email: thulasi@ece.concordia.ca

Memorial University of Newfoundland, Electrical Engineering. Applications are invited for a tenure-track position in Electrical Engineering in the area of digital and computer communications at the Assistant/Associate Professor rank depending on qualifications and experience commencing September 1994. Applicants must have a Ph.D. in Electrical Engineering with primary interests in digital communications, data communication networking and computer communications architecture. The successful applicant will be expected to teach undergraduate and graduate courses, conduct research, and participate in other educational, scholarly and professional activities. Applicants must have demonstrated ability to complement and expand the existing areas of expertise. Industrial and/or teaching and research experience is desirable. The successful candidate is expected to have/or seek a professional registration with the Association of Professional Engineers and Geoscientists of Newfoundland. The Electrical Engineering discipline has a well-established co-operative undergraduate and active graduate and research programs in power devices and systems and VLSI, and a proposed undergraduate option in computers and communications. Applicants should submit a curriculum vitae with the names of at least three referees, and three representative publications to: Dr. R. Seshadri, Dean, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, A1B 3X5. Reference: Elec-94-01. Fax #: (709)737-4042. The closing date for applications is March 30, 1994. In accordance with Canadian immigration requirements, this advertisement is directed to Canadian citizens and permanent residents of Canada. Memorial University of Newfoundland is committed to employment equity.

The Department of Electrical Engineering at The University of Maryland Baltimore County (UMBC) anticipates two regular full-time tenure-track faculty openings at the Assistant Professor Level. The department currently offers the M.S. and Ph.D. degree and emphasizes research in photonics, micro-electronics, signal processing, and communications. The successful candidates for these positions will be expected to participate in ongoing well funded research in the area of wavelength division multiplexed optical communication systems. This effort includes significant collaboration with local government and industrial research laboratories and the facilities available for this research include MBE, MOCVD, CAIBE, and several semiconductor processing clean rooms. One position will be reserved for the area of micro-electronics as it relates to opto-electronic device processing and packaging including lasers, detectors, modulators, amplifiers, and novel devices. The second position is reserved for research performed in the area of optical communication networks. The faculty member in the optical network area is expected to interact with the device team to help realize advanced WDM systems. Each faculty member is expected to teach at the graduate and undergraduate level, establish an active research program, and attract significant external funding. Please send a current c.v. and the names of three references to Professor Yung-Jui Chen, Department of Electrical Engineering, UMBC, Baltimore, MD 21228. Applications will be accepted until suitable candidates are found. The University of Maryland Baltimore County is an AA/EEO Employer.

Computer Science and Engineering, Northern Arizona University, Department of Computer Science & Engineering is seeking applications for a tenure track assistant professor beginning Fall 1994. A Ph.D. in Computer Science, Computer Engineering, Electrical Engineering, or associated field is required, and industrial experience is highly desirable. Preferred area of concentration is computer networking; the candidate must also be qualified to teach undergraduate courses in digital design and microprocessor systems. The position is contingent upon available funding. Applications will be reviewed as they are received. Direct inquiries and applications to Chair, Computer Engineering Screening Committee, College of Engineering & Technology, Northern Arizona University, Box 15600, Flagstaff, Arizona 86011-1560. Northern Arizona University is a committed Equal Opportunity/Affirmative Action Institution. Minorities, Veterans, Women and Persons with Disabilities are encouraged to apply.

Computer & Electrical Engineering faculty positions are available at Florida International University. Nominations and applications are invited for tenure track faculty positions at all levels in computer engineering and electrical engineering. The Department of Electrical and Computer Engineering at F.I.U. offers B.S., M.S., and Ph.D. degrees. Candidates must have an earned doctorate with a strong commitment to funded research, teaching and publications. Substantial USA funded research must also be shown by senior level applicants, plus good teamwork skills to work with faculty. Rank and salary are commensurate with qualifications and experience. Minorities and women are encouraged to apply. All applications post marked on or before April 7, 1994 will receive full consideration. The positions will be available starting August, 1994. U.S. citizens or lawfully authorized aliens should send a letter addressing the qualifications above, a resume, and three references (names) to Dr. Malcolm Heimer, Chair; Search and Screen Committee; Department of Electrical and Computer Engineering; Florida International University; Miami, Florida 33199. Florida International University is a state university located in Miami with over 24,000 students, of whom 1,800 upper division and graduate students are enrolled in the College of Engineering and Design. The School of Engineering has four departments: Electrical and Computer, Civil, Mechanical, and Industrial Engineering. Florida International University is an Equal Opportunity/Equal Access Employer and Institution.

Massachusetts Institute of Technology, Department of Mechanical Engineering: Assistant/Associate/Full Professor Appointments for Academic Year 1994-1995. Design (theory, methodology, optimization, CAD/CAM, AI techniques, design for manufacturing). Thermofluid Sciences (e.g., fundamentals of molecular and interfacial phenomena, multiscale transport processes in simple and complex fluids, and advanced diagnostics). Systems and Transportation (e.g., systems, information and transportation, broadly interpreted to include highway, rail and other transportation systems and/or any other large-scale systems involving primarily mechanical engineering disciplines). Appointees will be selected on the basis of intellectual strength and professional promise or accomplishments. They will be expected to teach and develop undergraduate and graduate subjects, to supervise graduate student research, and to establish independent spon-

sored research programs. Industrial experience is desirable. Doctorate in Mechanical Engineering or related field required. Applications including a resume (include citizenship and/or visa status), publications list, references and a 1-2 page statement of current and future research interests and goals should be submitted to Faculty Search Head (please specify position), Department of Mechanical Engineering, Massachusetts Institute of Technology, Room 3-173, Cambridge, MA 02139-4307. Resumes received after April 30, 1994 may not receive full consideration. An Equal Opportunity/Affirmative Action Employer.

University of Qatar, Doha, State of Qatar, Department of Computer Science. The Department of Computer Science of the faculty of science seeks applicants for a faculty position. Applicants must have a Ph.D. in Computer Science. The department is newly established and is in the process of expanding the scope of academic curriculum. The accepted candidate will join a staff of seven and will be expected to assist in formulating and implementing policy both for the present and future, in addition to day to day teaching and administrative duties. Applicants should send a resume, 2 photographs, and a list of three references to: The Dean, Faculty of Science, University of Qatar, P.O. Box 2713, Doha, State of Qatar.

The Swiss Federal Institute of Technology Zurich (ETHZ) invites applications for the position of an Assistant Professor of Mechatronics/Robotics. Duties will include research and teaching in the area of mechatronics with particular emphasis on the application to smallest structures, especially nano-robotics. The new professor should have a university degree, successfully completed own research work, and a proven ability to direct research projects. He/she will have to contribute to the teaching in mechatronics for students of mechanical and electrical engineering and computer science. Collaboration with various interdisciplinary research units at the ETHZ, with other national and international institutes, as well as with the industry will further be expected. The post of an assistant professor has been established to further the career of younger scientists. It is available for three years in the first instance, and renewable for another three years, and it offers a scientist with outstanding accomplishments the opportunity to be promoted to the rank of an associate professor (tenure track). Please apply with a curriculum vitae, a list of publications and a brief description of research interests to the President of the ETH Zurich, Prof. Dr. J. Nuesch, ETH Zentrum, CH-8092 Zurich, no later than April 15, 1994. The ETHZ specifically encourages female candidates to apply with a view towards increasing the proportion of female professors.

Senior Research Associate for University in Central Ohio. To conduct research in the modeling and analysis of antennas, electromagnetic radiation, and scattering from complex configurations, including code development to provide numerical predictions and setting up suitable experiments for verification purposes. Prepare technical reports for research sponsors as well as publish papers in scientific and technical journals. Supervise research work of students and technical support staff. Assist in the preparation of research proposals for government and private agencies. Requires a Ph.D. in electrical engineering and four years of research experience in electromagnetics which includes development and applications of advanced concepts in the area of high frequency ray and beam techniques or moment method code development and application, and in the area of numerical and hybrid techniques as well as in antenna/scattering measurements. Two positions will be filled. One full-time position, 40 hours per week within normal working hours, $35,000-$55,000/year. The second position is 20 hours per week within normal working hours, $17,500-$29,000/year. Qualified applicants reply immediately to Professor Leon Peters, Jr., ElectroScience Laboratory, The Ohio State University, 1320 Kinnear Road, Columbus, Ohio 43212.

Ecole Polytechnique of Montreal. The Department of Engineering Physics of the Ecole Polytechnique of Montreal, the largest French language engineering school in North America, offers a full-time tenure track position in nonlinear optics. Exceptional candidates in other fields will also be considered. We hope to fill the post in September 1994. The candidate will develop a research program in nonlinear optics, he will be expected to participate in teaching at all levels within the department, including laboratory courses, to direct graduate students, and to participate in various committees of the Ecole and of the department. Qualifications: Doctorate in engineering physics, in physics, or in a related discipline, with a specialty in optics; should have experience in nonlinear optics and should submit a research program of high quality in this field. Working knowledge of French required. Membership or qualification for membership in the Ordre des ingenieurs du Quebec an advantage. Salary: Salary, fringe benefits, and working conditions are determined by collective agreement. Application: Submit an application letter, a curriculum vitae, a description of previous experience and of research interests, a three-year research project including a budget, and names and addresses of three references, by May 15, 1994. These should be sent to: Prof. Arthur Yelon, Chairman, Departement de genie physique, Ecole Polytechnique de Montreal, C.P. 6079, succursale Centre-ville, Montreal (Quebec) H3C 3A7 Canada. Tel.: (514)340-4768, Fax: (514)340-3218. In accordance with Canadian immigration policies, preference will be given to Canadian citizens and landed immigrants. Ecole Polytechnique is an equal opportunity employer.

Faculty Positions, University of Notre Dame. The Department of Electrical Engineering has open faculty positions in two areas: Solid State Devices and Communication Systems. In the Solid State Devices area, one senior position and one junior (tenure track) position are open. Special attention will be given to individuals specializing in materials processing and characterization, optoelectronics, high speed devices, and integrated circuits. In Communication Systems, one junior (tenure track) position is open. Areas of interest include wireless, video, multimedia, and secure communication. Applicants should have a Ph.D. in Electrical Engineering or a related field. The Department offers B.S., M.S., and Ph.D. programs in Electrical Engineering and has 150 undergraduate students, 75 full time graduate students, and 22 faculty. Active research programs exist in two broad areas: Electronic Materials and Devices and Information Sciences and Systems. Applicants should have interest in teaching at the undergraduate and graduate levels, advising students, and conducting research. Rank and salary are negotiable. Interested persons should submit a complete resume and names of references to: Dr. Daniel J. Costello, Chairman, Department of Electrical Engineering, University of Notre Dame, Notre Dame, Indiana 46556. The University of Notre Dame is an Affirmative Action/Equal Opportunity Employer.

University of Texas at San Antonio: The Electrical Engineering Program invites applications for two tenure-track faculty positions. One position is at the Assistant Professor level, and another position is at the Associate Professor level. Candidates are sought in the areas of communications with emphasis on telecommunications, cellular networks, data compression and networking; and signal and image processing with emphasis on bio-signal and image processing. Applicants should have an earned Ph.D., demonstrated research ability and a strong interest in graduate and undergraduate teaching. You must specify in your cover letter what level of position you are applying for. Salary commensurate with qualifications and experience. UTSA is a comprehensive metropolitan university located on the edge of the Texas hill country. San Antonio combines a rich cultural heritage with a modern focus on education, research, and technology. Send resume, a summary of your specific expertise in one of the above areas, names of four references with addresses and phone numbers, by April 2, 1994 to: Chair, Electrical Engineering Search Committee (EE-5), Division of Engineering, University of Texas at San Antonio, San Antonio, TX 78249-0665. UTSA is an equal opportunity and affirmative action employer. Minorities and women are encouraged to apply.

California State University, Hayward invites applications for a tenure-track position (#94-95 TELE-TT) for Fall 1994 in its telecommunications option program. Teaching will range from the protocol level to business applications. A commitment to teaching and research necessary. Ph.D. or ABD is required, with an emphasis in telecommunications. Other closely related terminal degrees will be considered. Send resumes by March 25 to Dr. Vernon Kam, School of Business and Economics, California State University, Hayward, Hayward, CA 94542. AA/EOE.

Electrical Engineering. The University of North Florida (UNF) invites applications for three nine-month tenure track faculty positions starting in August 1994. Two positions will be at the assistant professor level and a third will be associate or full professor. Minimum qualifications are a doctorate in electrical engineering or closely related field and demonstrated excellence in undergraduate teaching. Candidates are sought in communications, controls, and electronics. Other considerations include related academic and industrial experience, research productivity and promise, potential for obtaining external support and professional registration. UNF is a growing urban state university with 10,000 students and a strong commitment to undergraduate education. Send letter of application, vita, transcripts and three letters of recommendation to EE Search, Electrical Engineering Department, University of North Florida, Jacksonville, FL 32224-2645. Phone (904) 646-2970, Fax -2975, EESEARCH@unflvm.bitnet. Applicants seeking associate or full professor rank must indicate that in the letter of application. Screening of applications will begin 31 March 1994 and will continue until all positions are filled. Women and minorities are encouraged to apply. UNF is an Affirmative Action/Equal Access/Equal Opportunity Employer.

Oregon State University - The Department of Electrical and Computer Engineering invites applications for a tenure-track, Assistant Professor position in the area of power electronics and drives. Candidates should have an earned doctorate in Electrical Engineering or in a related field and are expected to have a strong commitment to high quality undergraduate and graduate teaching and to the development of a sponsored research program. With a faculty of 25, the Department of ECE enrolls about 425 undergraduate and 120 MS/PhD students. The department offers ABET accredited programs in electrical and computer engineering. High technology corporations such as Hewlett-Packard, Intel, Mentor Graphics, and Tektronix have major operations in the area and provide support for the electrical and computer engineering programs. The Energy Systems group works closely with the Bonneville Power Administration, the Electric Power Research Institute, Puget Power, and other West Coast utilities. The Department has modern facilities housed in a new building. Located in the Willamette Valley 80 miles south of Portland, OSU and the city of Corvallis offer a beautiful and unspoiled environment and many cultural activities. Applications must include a comprehensive resume, a list of three to five professional references, and a letter of interest. Please send material to Chairman, ECE Search Committee, ECE Department, Oregon State University, Corvallis, OR 97331-3211. Review will begin April 1, 1994, and continue until the position is filled. Oregon State University is an Affirmative Action/Equal Opportunity employer and complies with Section 504 of the Rehabilitation Act of 1973.

Kansas State University-Salina engineering technology department invites applications for a tenure track position with responsibilities in both electronic engineering technology and the mechanical engineering technology programs. M.S. in Engineering or Engineering Technology & 3 yrs. of relevant industrial experience. Call 913-826-2672 for an information packet. KSU is an equal opportunity/affirmative action employer & actively seeks diversity among its employees.

Director, The Center for Advanced Computer Studies. The University of Southwestern Louisiana. Nominations and applications are sought for the position of Director of The Center for Advanced Computer Studies (the Center). The financial package includes a competitive salary, an administrative stipend and a discretionary fund. The candidate may also be considered for appointment to an endowed research professorship, depending on qualifications. About The Center: The Center is primarily a research unit, with MS and PhD degree programs in computer science and computer engineering. About 200 students are enrolled in the graduate programs, of which about 100 are pursuing a PhD degree.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

Related programs include the CSAB accredited undergraduate program administered by the Department of Computer Science, with an enrollment of 350 students, and the ABET accredited undergraduate program in the Department of Electrical and Computer Engineering, with an enrollment of 370. The Center has currently about 20 research faculty members. A typical teaching load is one graduate course per semester and a continuing research seminar. External grants/contracts (over three million dollars in 1992-93) support research in a variety of areas. The Center has state-of-the-art research and instructional computing facilities, consisting of several networks of Sun workstations that operate under a UNIX environment. In addition, the Center has dedicated research laboratories in Artificial Intelligence, Computer Vision & Pattern Recognition, Intelligent Robotic Systems, Software Engineering, and Very Large Scale Integration. Lafayette is situated in Acadiana, the home of the world renowned Cajun cuisine. It has a population of 94,000 and is approximately 120 miles west of New Orleans. Qualifications for the Director: The candidate must have a PhD in computer science/engineering and demonstrated abilities in academic and administrative leadership. He/She must have national visibility through accomplishments in research, contract and grant funding, professional activities, etc. The candidate must be able to enhance and promote collaboration with government agencies and industrial corporations. The search committee will begin reviewing applications on April 1, 1994 and continue until the position is filled. Applications/nominations containing statements of academic, professional and administrative credentials, a detailed resume and names of five references are to be mailed to: Dr. Vijay V. Raghavan, Professor, Chairman, Search Committee for the Director, The Center for Advanced Computer Studies, The University of Southwestern Louisiana, Lafayette, LA 70504-4330, Phone: (318) 231-6603. An Equal Opportunity/Affirmative Action Employer.

The Department of Electrical Engineering at the University of Tulsa has a tenure track position beginning Fall, 1994. A specialist in communications with emphasis on fiber-optics is preferred, but applicants from other related research areas are encouraged to apply. Industrial experience in research and development is especially desirable. This position requires an earned doctorate, a commitment to undergraduate education, and the ability to initiate and participate in interdisciplinary research programs both within the University and with local industry. Rank and salary will be commensurate with qualifications. Departmental computer facilities include a Sun SPARC workstation complex and a PC Network in the undergraduate laboratories. The Department is an integral part of a campus-wide computer network with access to college workstations and mini supercomputers, the University mainframe, and the national networks. The University of Tulsa is a private, selective-admission institution of 3000 undergraduate and 1500 graduate students, located in an urban community of over half a million. Interested persons should send resume, including names, addresses and phone numbers (or E-mail address) of three references by April 1, 1994 to: Dr. Gerald R. Kane, Professor and Chair, Department of Electrical Engineering, The University of Tulsa, 600 So. College, Tulsa OK 74104. The University of Tulsa is an affirmative action/equal opportunity employer.

Arecibo Observatory, Puerto Rico. Transmitter and RF/Microwave Engineer. The National Astronomy and Ionosphere Center, headquartered at Cornell University, invites applications for the position of transmitter and RF/microwave engineer. The Observatory's research activities in radio and radar astronomy and atmospheric science center around the use of the 1000-ft diameter antenna, which includes 430 MHz and 2.2 GHz radar transmitters. A major NSF/NASA-supported upgrade of the 1000-ft telescope is currently underway, which includes a new 2.2 GHz transmitter, broadband receivers and extension of the upper frequency limit to the 8 - 10 GHz range through an all-reflective feed system. The transmitter and RF/microwave engineer will work in the Electronics Department at Arecibo to maintain existing transmitter and receiver systems, to assist in developing specifications for new systems, and to install and test new equipment. He/she will also be involved in the design and fabrication of various other systems, including low-noise front ends, IF/LO chains, and signal processing electronics. Consequently, a wide variety of expertise in many of these areas is extremely important. A BS or MS degree in electrical engineering is required, along with 5 to 10 years minimum experience. The successful candidate will be an employee of Cornell University, and eligible for all of the University's normal benefits, including health benefits, generous vacation time, and assistance with moving expenses to and from Puerto Rico. Applications should be received by April 1, 1994. Please reply to Dr. Paul Goldsmith, Director NAIC, 502 Space Sciences Building, Cornell University, Ithaca, NY 14853-6801. Cornell University is an equal opportunity/affirmative action employer.

Position Announcement. Louisiana Tech University, Department of Biomedical Engineering. The Biomedical Engineering Department at Louisiana Tech University invites applications for the position of Assistant Professor. The Department is seeking applicants with academic training/experience in bioinstrumentation and rehabilitation engineering to complement department's research and service activities. Applicants will be expected to teach undergraduate/graduate courses and direct graduate-student research. Candidates must have ability to establish an externally-funded research program. The Biomedical Engineering Department offers a nationally-recognized academic program with emphasis on systems physiology and rehabilitation engineering. Degrees are offered at the B.S. (ABET-accredited), M.S. and Ph.D. levels with an enrollment of approximately 150 undergraduate and 35 graduate students. Research and service activities are conducted through the Department's Board of Regents-funded Center for Rehabilitation Science and Biomedical Engineering. The University is developing world-class resources for development of micro-structures, devices and systems. Opportunities exist to interact with the Institute for Micromanufacturing and LSU School of Medicine in Shreveport. Candidates for the position must have earned a doctorate in Biomedical Engineering or related field, and be U.S. citizen/permanent resident. Send curriculum vitae, statement of teaching and research interests/goals, and names and addresses of at least three references to Dr. Stan A. Napper, Chair of Search Committee, Biomedical Engineering Department, Louisiana Tech University, P.O. Box 10348, Ruston, LA 71272 (phone 318-257-2645). The appointment begins September 1, 1994. Applications will be reviewed as received until position is filled. Louisiana Tech University is an equal employment university. Women and minorities are encouraged to apply.

Government/Industry Positions Open

Systems Analyst/Consultant: Provide consultancy at customer locations to analyze, design, develop, test, modify and re-engineer integrated product support, warranty administration, reliability analysis and dealer polling systems for large manufacturers and dealers, using IMS DB/DC, DB2, VSAM, ISPF-PDF, TSO, RMDS, XPEDITER, BTS, JCL, CASE tools (ADW), FILE-AID (IMS DB2 MVS) and VIA/Insight on a network of IBM-3090s and PS/2 PC workstations under MVS/ESA/XA, OS/2, and MS-DOS operating systems utilizing various languages such as COBOL, APS, SQL, REXX, CLIST, MFS and ISPF-DTL; Develop test scenarios and perform testing using state-of-the-art testing tools and debuggers such as TRAPS, XPEDITER and BTS; Generate COST VS REVENUE, Performance, decision support and various statistical reports from different data sources using SQL and QMF. Require: B.S. in Computer/Electronics Engineering with two years of experience; Extensive (50%) paid travel on assignments within the U.S. is required. Salary: $42,500/year, 40 hrs/wk. Interview/job site: South Laguna, CA. Send this ad and your resume to Job # LP 1161, P.O. Box 269065, Sacramento, CA 95826-9065.

Tele Danmark Research - Research Fellowship. Applications are invited for a research fellowship (of duration 1-2 years) for research on Broadband Optical Networks. The successful applicant will be involved in the research on fiber optic access networks and on the general future telecommunications network topology. Close interaction with the work on updating of the current network operated by the regional Danish telephone companies is planned. Economical as well as technical objectives are of importance in the work. A solid background in optical communications as well as in the area of optical (access) networks is required. Tele Danmark Research is owned by Tele Danmark Inc. which is the shareholder company for the regional Danish telephone companies. Tele Danmark Research carries out long term research for Tele Danmark Inc. Applicants are at least required to have a PhD. The salary level will match the academic level of the applicant. Applicants on professor level might benefit from special tax rules for foreign researchers. For more information contact Gunnar Jacobsen or Bjarne Tromborg using telephone (+45) 45 76 64 44 or fax (+45) 45 76 63 33. Interested qualified applicants should send a letter of application, curriculum vitae and letters of recommendation to: Research Director Erik Nilsson, Tele Danmark Research, Lyngso Alle 2, DK-2970 Ilorsholm, Denmark, not later than May 1, 1994.

Engineer. We are a large, privately-owned electric utility seeking a professional with a BSEE (emphasis in electric and magnetic field theory) and 10+ years experience in inductive coordination between electric utilities and railroad/pipeline systems. Knowledge of railroad communication and signaling systems is preferred. An exceptional compensation and benefits package are available. Forward resume to: P.O. Box 767, Chicago, IL 60690. EOE m/f/d/v.

Senior Engineer. Opening with worldwide trade association for graduate Electrical or Mechanical Engineer with A.C. and/or D.C. motor design experience. Must be computer literate, have good speaking and writing abilities, and have good organizing skills. Send resume and salary requirements to Electrical Apparatus Service Association, 1331 Baur Blvd., St. Louis, MO 63132.

Software Engineer wanted for working on a digitizer and interconnection of multiple tools used for logging. This includes designing complete kernel and operating system for embedded environment consisting of self-contained Motorola IMP MC68302 microcontrollers and AT&T DSP32C digital signal processors, along with the associated peripheral hardware; design providers of all functions such as input/output drivers, memory allocation, CPU and JOB scheduling, interrupt handling, serial/parallel DMA, serial communication protocols; developing real time software in assembly language for AT&T DSP32C and Motorola IMP MC68302 and then intermixing it with C language; writing drivers for interconnecting multiple MC68302 IMP, using HDLC and UART protocols to establish a network of tools; writing drivers to interface AT&T DSP32C and Motorola IMP MC68302, and similarly among multiple DSP32Cs; debugging and modifying hardware using advanced equipment like ICE, logic analyzer, high speed oscilloscopes and PLD/EPROM programmer; Reqs. Master's in Computer Engg., and 1 yr. exp. in job offered or 1 yr. related exp. as Systems Engineer. Must have 1 univ. course in each of the following: Parallel Processing, Computer Networks and Digital Communications, Operating System, Mini- & Micro-computers and Design of Electronic Circuits; and 1 grad. course in which programs were developed in C and Assembly languages for digital signal processors; $38,000/yr., 40 hrs./wk., 8am-5pm. Send resume to Oklahoma State Employment Service, 11654A E. 21st St., Tulsa, OK 74129 (ID#7209) Job Order No. 080908.

Senior Electro-Mechanical Engineer. Supervise one electrical engineer and one mechanical engineer in the development, design and field installation, testing, maintenance and repair of ATMS (automatic teller machines) and other electro-mechanical devices and systems such as medical monitoring devices containing CRTs (cathode ray tubes) and electromechanical connectors and housing for OEM (original equip-

ment manufacturer) equipment and systems from customer specifications. Applying principles and techniques of both electrical and mechanical engineering, design electronic circuitry, including analog circuitry, digital circuitry, deflection processor circuitry, and universal power supply with auto sensing, and mechanical connectors and housings for electromechanical circuitry, to conform with customer specifications and requirements. Determine methods, procedures, and conditions for testing equipment and systems. 40 hrs/wk. Overtime as necessary. 8 a.m. to 5 p.m. Mon. to Sat.* $43,150/year. Must have bachelors degree in electrical engineering and three years experience in the offered position or three years experience as a senior electrical engineer. For the required design of electro-mechanical components, must have completed at least four (4) college courses in electromechanical technology, mechanical engineering, or mechanics. The experience required above must have involved work with electromechanical products incorporating CRTs electronically linked to mechanical components. *As frequent overtime is required, more often than not it includes a Saturday. Must have proof of legal authority to work permanently in the U.S. Send two (2) copies of resume to Illinois Department of Employment Security, 401 S. State St., 3-s, Chicago, IL 60605, Attn: Len Boksa, Ref. No. V-IL-11332-B. No calls. An employer paid ad.

Engineer, Sr. Components Design: To evaluate and adapt state-of-the-art testability techniques and tools; develop scan-based diagnosis techniques and detailed test methodologies for use in developing high-performance VLSI chip. Requires Ph.D. in E.E., academic project/rresearch background in sequential circuit test pattern generation, partial scan and distributed computation, and development of scan flip flop selection heuristic; also testability techniques, full scan design methods, logic and fault simulation principles, test algorithms, CMOS VLSI logic design, data structures, UNIX, C-Shell, and programming in C/Pascal; course work in fault-tolerant computing, algorithmic logic design; knowledge of boundary scan techniques. $5,517.60/month. 40 hrs/wk. Place of employment and interview: Folsom, CA. Send this ad and your resume or letter of qualification to: Job Order #HR46058, P.O. Box 269065, Sacramento, CA 95826-9065. The company is an equal opportunity employer and fully supports affirmative action practices.

Engineer, Senior Design: Responsible for architecture verification and design analysis of company's prospective next-generation microprocessor and derivative microprocessors; incorporate & develop new CAD/verification tools to perform architecture validation functions; develop new diagnostic programs & random instruction code generator using the AS64 assembly language to improve microprocessor functional test coverage. Ph.D. in Computer Science and Engineering or Computer Science or Computer or Electrical Engineering. Academic project/research background or coursework in: VLSI circuit & System/logic design; CAD tools for VLSI design; multiprocessor systems; computer performance simulation; queuing network simulation; caching schemes; microprocessor design; computer architecture; logic simulation; X86 Assembly language programming; C & C++; and UNIX operating system. $4,935/mo.; 40 hrs./wk. Place of employment and interview: Santa Clara, CA. If offered employment, must show legal right to work. Send this ad and your resume to: Job No. WL 41168, P.O. Box 269065, Sacramento, CA 95826-9065. The company is an equal opportunity employer and fully supports affirmative action practices.

Systems Design Consultant: To design, implement, and consult on Energy Management Systems for Electric Utility industries; to design and implement software for Open Systems Architecture Environments with use of C and UNIX (UNIX internals), and Graphical User Interfaces with use of X windows/Motif-based programming techniques. Leads R & D activities. Minimum Qualifications: 1) Master's degree in Computer Science with Bachelor's degree or equivalent level education in Electrical Engineering, 2) 5 years of experience in this position or Systems Design Engineer/Software Engineer position(s) in Energy Management Systems for Electrical Utility industries, with 3 years of such experience involving a) Software designing and implementation in Open Systems Architecture Environments with use of C and UNIX (UNIX internals), b) Graphical User Interface designing and implementation, and c) Use of X windows/Motif-based programming techniques. 9 a.m. to 6 p.m. 40 hours/wk. $40,000/year. Send cover letter and resume to S. Springmeyer #4-5, MDJT, 390 North Robert Street - 3rd Floor, St. Paul, MN 55101. Must be authorized for permanent employment in the United States.

User Support Analyst Supervisor for Import-Export company. Hours 9 to 5 p.m. 40 hours p/w. $13.80 p/h. OT. $20.70 p/h. Duties: Supervises and Coordinates activities of workers who provide problem-solving support to computer users; Assists in solving nonroutine software, hardware, and procedure problems, using computers and manuals. Talks with staff, computer users, supervisors, and managers to determine requirements for new or modified software and hardware. Writes recommendations for management review. Coordinates installation of hardware and software implementation of procedure changes. Please submit resume only to the Job service of Florida at 701 S.W. 27 Avenue, Room 15, Miami, Florida 33135, Re: Job Order #FL0966071.

Paradigm Shift, Inc., Software Trainer/Consultants. Paradigm Shift, Inc. is seeking candidates for the positions of Software Trainer/Consultant in C++, and Software Trainer/Consultant in Smalltalk. The ideal candidates will meet or exceed the following requirements: Ph.D. in Software Engineering or equivalent, 10 years experience in industrial systems software and development, 3 years experience in OOP, demonstrated excellence in teaching, willingness to travel minimum 30 weeks per year. The job responsibilities include: Train clients in OOP, OOD, and OOA to provide optimal technology transfer to the OO paradigm. Provide consulting that guides client's process and architectural and design decisions, develop training material, develop software components. Compensation will be base salary plus bonus for each week traveled. Total starting range $75,000 - $115,000 plus generous benefit package. Relocation to the corporate location is not required at this time. Applicants should contact John Meyers, Product Manager, at Paradigm Shift, Inc., P.O. Box 5108, Potsdam, NY 13676, Fax 315-353-6110, meyers@parashift.com

Experienced Electronics Engineer: Center for Remote Sensing is a small high-tech R & D organization. We are in immediate need of exceptionally brilliant electronics engineer with interest and experience in diverse areas of electronics. The expertise should include analog, RF, microwave, digital and PC based systems design (Both hardware and software, assembly and C). This is a senior level and responsible position. We provide excellent salary and benefits. Please write to: CRS Employment, P.O. Box 9244, McLean, VA 22102.

Project Engineer. Master's in elec. eng. or electromechanical eng. & 3 yrs.' exp. in research, design, application & testing of switched reluctance motors used as actuating devices & for continuous operating conditions. Exp. must include work with magnetic finite & boundary element analysis. Serve as project engineer with respect to the research, design, application & testing of switched reluctance motors used as actuating devices & for continuous operating conditions. Analyze current production & prototype switched reluctance motors, drive systems & sensing methods for automotive applications, including electronic throttle control & clutch control systems. Perform feasibility studies & new product development as well as magnetic finite & boundary element analysis. Develop cost effective sensorless position tracking system. Apply switched reluctance motor technology to existing products. Advance the state-of-the-art in overcoming traditional negative characteristics such as excessive torque ripple & noise via non-electronic control means. Sal. Range: $45,220-$55,000 per yr. dep. on qual. 40 hrs./wk. 8:00-4:30. Employer Paid Ad. Send resumes to: 7310 Woodward Ave., Rm. 415, Detroit, MI 48202. Reference No. 109393.

Engineer, Senior CAD: Develop numerical algorithms, compatible device modeling & software systems for fast, accurate circuit simulation in applications crucial to the design of VLSI circuits such as circuit performance analysis, multi-conductor/multi-medium interconnects, electromigration & circuit reliability; develop open software characterization system for device analysis, process file generation & statistical analysis. Ph.D. in Electrical and/or Computer Engineering. Academic project/research background in: developing algorithms & software systems for simulating large size circuits; numerical algorithms, device modeling & data base for fast, accurate & memory-efficient simulation of VLSI circuits; circuit theories; electrical engineering, including solid state devices, electromagnetics & communication theories; mathematics; ECAD software systems; and programming C and Fortran; academic coursework in digital circuit design, circuit simulation and software engineering. $5,050.00/mo.; 40 hrs./wk. Place of employment and interview: Santa Clara, CA. If offered employment, must show legal right to work. Send this ad and your resume to: Job No. HR 46077, P.O. Box 269065, Sacramento, CA 95826-9065. The company is an equal opportunity employer and fully supports affirmative action practices.

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'Every engineer a leader'

With this theme, the IEEE-USA Careers Conference next month will examine ways to develop the leadership potential of the engineering community. The venue is the Worthington Hotel in Fort Worth, Texas, and the dates, April 14–15.

The conference, meant for human resources and engineering managers, engineers, academics, and other technical professionals, will explore how organizations can help their engineers take charge at many levels, thereby obtaining a competitive advantage in today's changing workplace.

Workshop sessions include: leadership skills in the present economic environment; achieving a diverse workforce in a declining economy; resettling displaced engineers; the role of education in developing engineer leaders; the changing workplace and its implications for engineers; and case studies in building leadership at every level.

A post-conference workshop on April 16, "Careers in transition," will deal with the needs of engineers and managers who are contemplating job moves or are in the throes of change within their own companies.

For information, contact Marilyn Sumpter at IEEE-USA, 1828 L St., N.W., Suite 1202, Washington, DC 20036-5104; 202-785-0017; fax, 202-785-0835; e-mail, s.grayson (Compmail) or s.grayson@ieee.org (on the Internet).

A job-matching service for engineers

IEEE-U.S. Activities has reached an agreement with an electronic matchmaking career service, called Job Bank USA, that will provide information about employment opportunities to IEEE members and their spouses. A national service based in McLean, Va., Job Bank is used by such large companies as IBM, Xerox, and Boeing.

An employer pays for a local, regional, or national job search. Within 48 hours, Job Bank pulls prospective matches from its database. Individuals are notified of candidate companies before any confidential information like a résumé is released.

One year of the service, which includes newsletters and an updated résumé, is being offered to IEEE members and spouses for $27 until March 31. (The usual fee is $75.) More information is available from Job Bank USA at 800-296-1USA or 703-847-1706. IEEE-USA can be reached at 202-785-0017.

Coming
in Spectrum

FOCUS ON WORKSTATIONS AND PCs. With their falling prices and growing power, engineering workstations are achieving price-performance levels that turn dreams into reality. In its annual report on this vital marketplace, *IEEE Spectrum* focuses on the workstations and personal computers that deliver high performance yet cost less than US $7000. What should one look for in such a workstation? And what features are available? *Spectrum* provides the answers, as well as a table of the latest low-cost systems.

PERSONAL COMMUNICATIONS SERVICES. The next milestone for the infant PCS industry is in early May when licenses and permits are issued in the United States for the first systems. This overview considers what to be concerned about as the systems evolve.

DIVERSITY'S EFFECTS. A study of 3000 scientists and engineers at R&D facilities in the United States found that the possession of a Ph.D. affects people of different demographic backgrounds differently. The authors of the study examine how these differences may influence performance on the job and perceptions of others' contributions.

EEs ON THE BOARDS. This small but growing minority of corporate directors can be critical to a business's success. *Spectrum* looks here at the contributions electrical engineers are making to the boards of Atlantic Richfield, Federal Express, General Motors, Hitachi, IBM, and others.

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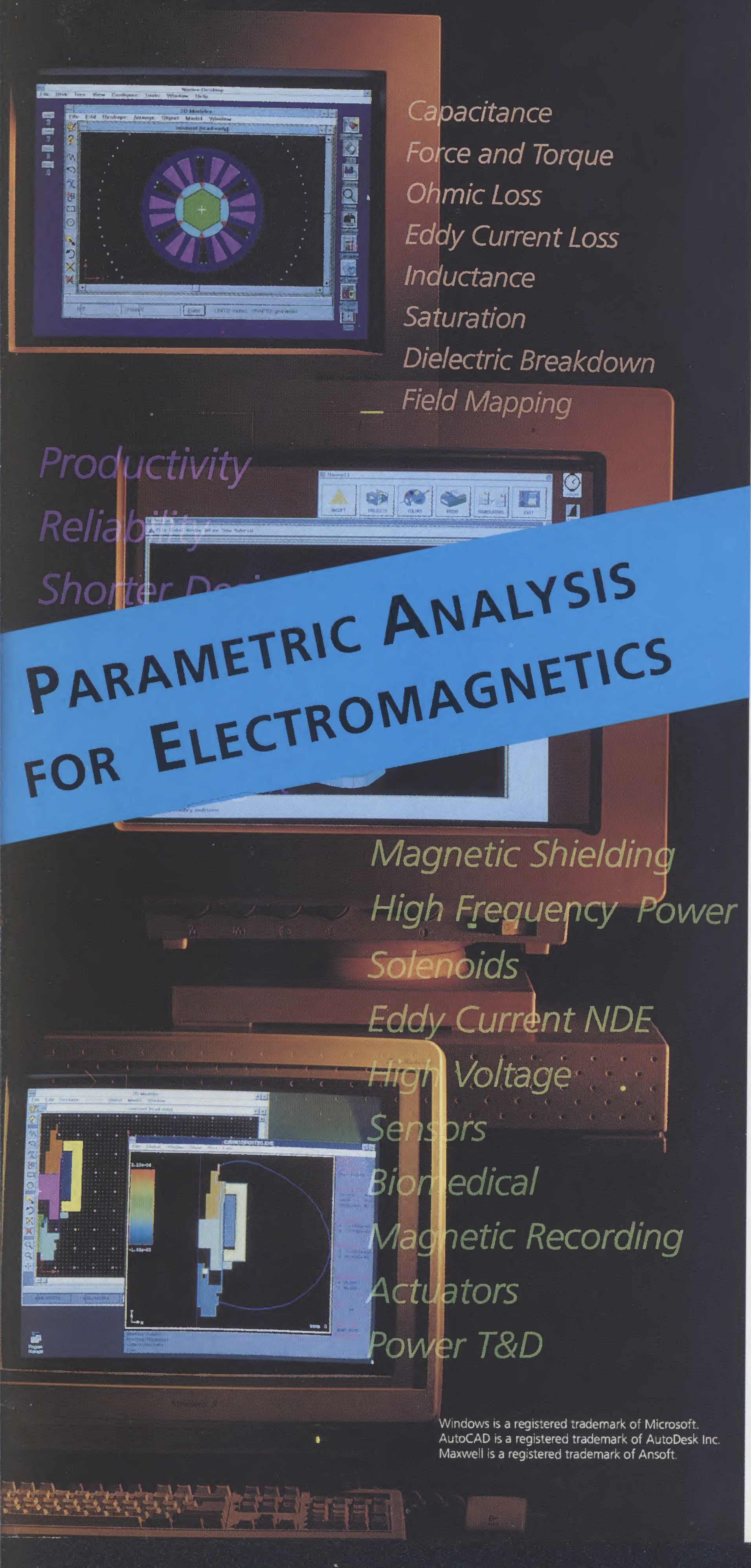

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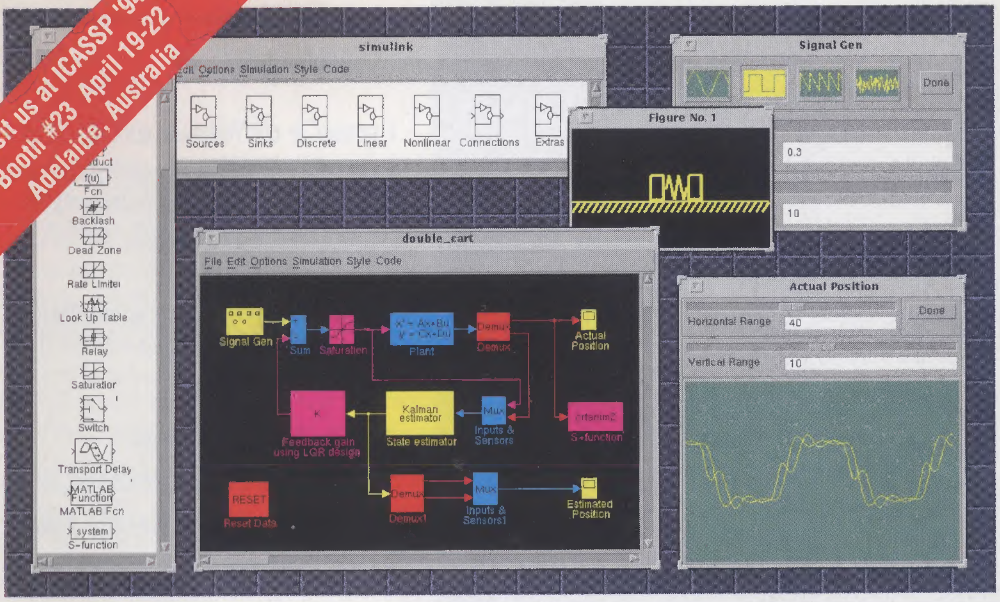

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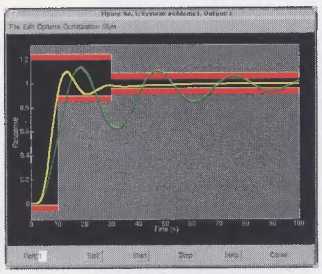

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For Belgium, Luxembourg, The Netherlands, United Kingdom and Republic of Ireland call Cambridge Control, Ltd: +44-223-423-200 **or** Rapid Data, Ltd: +44-903-821-266

Circle No. 4